

**EXHIBIT L**

## Uranium\*

### Guideline

*The interim maximum acceptable concentration (IMAC) for uranium in drinking water is 0.02 mg/L (20 µg/L).*

### Identity, Use and Sources in the Environment

Uranium occurs naturally in the +2, +3, +4, +5 or +6 valence states, but most commonly in the hexavalent form. In nature, hexavalent uranium is commonly associated with oxygen as the uranyl ion,  $\text{UO}_2^{2+}$ . Naturally occurring uranium ( $^{238}\text{U}$ ) is a mixture of three radio-nuclides ( $^{234}\text{U}$ ,  $^{235}\text{U}$  and  $^{238}\text{U}$ ), all of which decay by both alpha and gamma emissions.<sup>1,2</sup> The alpha energies are all clustered around 4.5 MeV. Natural uranium consists almost entirely of the  $^{238}\text{U}$  isotope, with the  $^{235}\text{U}$  and  $^{234}\text{U}$  isotopes constituting about 0.71% and 0.0057%, respectively<sup>3</sup>; 1 µg of natural uranium has an activity of 0.025 Bq.<sup>1</sup> Uranium is widespread in nature, occurring in granites and various other mineral deposits.<sup>2,4</sup>

The United States, Canada and South Africa produce approximately 80% of the uranium in the western world.<sup>3</sup> It is estimated that more than 13 million kilograms were produced in Canada in 1987.<sup>5</sup> Uranium is used mainly as fuel in nuclear energy plants.

Uranium is present in water supplies as a result of leaching from natural deposits, its release in mill tailings, emissions from the nuclear industry and the combustion of coal and other fuels.<sup>1,6-8</sup> Phosphate fertilizers, which may contain uranium at concentrations as high as 150 mg/kg, may also contribute to the uranium content of groundwater.<sup>9</sup>

### Analytical Methods and Treatment Technology

Uranium in water is most commonly measured by solid fluorimetry with either laser excitation or ultraviolet light following fusion of the sample with a pellet of carbonate and sodium fluoride (detection limit 0.1 µg/L).<sup>10</sup> Sample preparation for this method is tedious, however, and there is interference from other metals. Uranium can also be determined by inductively coupled plasma mass spectrometry, which has the same detection limit (0.1 µg/L) and a between-run precision of less than 6%.<sup>11</sup> Alpha spectrometry has been used for the determination of uranium in bottled waters<sup>12</sup> and environmental media,<sup>13</sup> although the recovery is often highly variable owing to the low specific activity of natural uranium.<sup>13</sup> Kinetic phosphorescence analysis shows promise as a sensitive and selective method for the analysis of uranium and other lanthanides in drinking water and other media.<sup>14</sup>

The effectiveness of water treatment processes for uranium removal has not been well documented in full-scale treatment plants. Laboratory studies and pilot plant tests have shown that conventional anion exchange resins are capable of removing uranium from drinking water supplies to concentrations as low as 0.1 µg/L (99.9% removal). Gamma radiation buildup in the uranium removal system does not appear to be a health concern.<sup>15</sup> However, because uranium is highly preferred by anion resins, regeneration may be difficult.<sup>16</sup> A number of other treatment methods, including conventional coagulation, lime softening, activated alumina and reverse osmosis, have also been found to reduce uranium concentrations to 1–5 µg/L (>90% removal) in laboratory and pilot plant studies.<sup>17-20</sup> Uranium complexes that occur in natural water have been removed experimentally by nanofiltration at efficiencies in the range of 90–98%, depending on the type of nanofiltration membrane employed.<sup>21</sup> Although cation exchange and granular activated carbon can remove uranium effectively at controlled pHs and for limited duration, they are not considered practical methods for drinking water

\* This review addresses only the chemical aspects of uranium toxicity. Information pertinent to the derivation of a guideline based on radiological effects is discussed separately in a Criteria Summary on radiological characteristics.

## Uranium (10/99)

treatment.<sup>16</sup> Feed water matrix effects (e.g., presence of ions other than uranium) influence the uranium removal efficiency, especially with ion exchange and, to a limited extent, reverse osmosis technologies.<sup>22</sup>

In areas with high natural uranium levels, it may be difficult to achieve low final uranium concentrations (i.e., <5 µg/L) with the treatment technology available.<sup>23</sup> Using ion exchange, for example, uranium removal efficiency is reduced when the uranium concentration in the feed water is high (e.g., >100–500 µg/L), and the uranium level in the treated water will be around 10 µg/L.<sup>22</sup>

### Exposure

Uranium concentrations of up to 700 µg/L have been found in private groundwater supplies in Canada.<sup>24,25</sup> In a 1980–81 survey of 13 selected sites in south-central British Columbia, the mean uranium concentration (n = 519) in surface water and groundwater (some treated) supplies was 4.06 µg/L.<sup>26</sup> The mean and median levels of naturally derived uranium in groundwaters of 287 wells sampled in southeastern Manitoba (1982–84) were 58.3 µg/L and 10 µg/L, respectively; the maximum value was 2020 µg/L.<sup>27</sup> Uranium levels were highest in Precambrian rock aquifers (average 115.6 µg/L) and lowest in Paleozoic sedimentary rock aquifers (average 3.5 µg/L). In a radionuclide survey (n = 154) carried out by the Radiation Protection Bureau, Health Canada, in Manitoba in 1984 and 1987, levels of uranium ranged from less than the detection limit (5 µg/L) to 96 µg/L, and the mean concentration for samples with levels greater than the detection limit (45% of samples) was 16.1 µg/L.<sup>28</sup> In another survey conducted by Health Canada between 1975 and 1986, uranium was not found at concentrations above the detection limit (5 µg/L) in raw and treated water samples from Alberta, British Columbia, New Brunswick, Newfoundland, Nova Scotia, Quebec and the Yukon. Uranium levels above 5 µg/L were detected in water samples from Saskatchewan (80/243 samples; range 5–51 µg/L), Manitoba (7/88 samples; range 6.1–26 µg/L), Ontario (7/629 samples; range 5.2–39 µg/L) and the Northwest Territories (9/12 samples; range 19–2500 µg/L).<sup>29</sup> In a 1990–95 survey of 130 sites (approximately 3700 samples) in Ontario, the mean of the average uranium concentrations (range <0.05–4.21 µg/L; detection limit 0.05 µg/L) in treated drinking water was 0.40 µg/L.<sup>30</sup> In Quebec, uranium was detected (detection limit <5 µg/L) in only 1.7% of samples (n = 2809) taken between 1993 and 1996 (range <5–20 µg/L)<sup>31</sup>; the survey encompassed more than 5.9 million individuals. In a 1994–95 survey of 322 wells in the Kitigan Zibi First Nation community in Quebec, uranium was detected (n = 525) at levels ranging from 0.01 to 1481 µg/L, with mean and median levels of 5.1 µg/L and 5.2 µg/L,

respectively; levels in surface water (n = 11) were less than 1.1 µg/L.<sup>32</sup> Multiple sampling in some of the wells revealed wide fluctuations in uranium levels within individual wells. For example, the concentration in one well was approximately 400 µg/L on July 14, 1994, >1400 µg/L on September 1, 1994, and just over 200 µg/L on February 6, 1995. No correlations were found between the uranium concentrations and pH, redox, total dissolved solids, hardness, anions, well depth or temperature.<sup>32</sup> In New Brunswick, the mean uranium concentration from 1382 samples taken between 1994 and 1997 was 1.83 µg/L.<sup>33</sup> In a 1981 survey of 72 municipally treated systems in Nova Scotia, 98.6% of the samples tested were found to have uranium levels below 10 µg/L.<sup>34</sup>

A mean uranium concentration of 2.55 µg/L was reported in drinking water from 978 sites in the United States in the 1980s.<sup>35,36</sup> The mean concentration of uranium in drinking water in New York City ranged from 0.03 to 0.08 µg/L.<sup>37</sup> In five Japanese cities, the mean uranium level in potable water supplies was 0.9 ng/L.<sup>38</sup> Uranium may leach into water from uranium-bearing glass items (maximum of 30 µg/L) or from ceramic-glazed items in which uranium is used as a colouring agent (approximately 300 mg/L).<sup>39</sup>

On the basis of the results of the survey from Ontario,<sup>30</sup> the daily intake of uranium from drinking water for an adult consuming 1.5 L/d is estimated to be 0.6 µg.

Uranium has been detected in a variety of foodstuffs, with the highest concentrations being found in shellfish. The concentrations of uranium in muscle (dry weight) from fish caught in a Canadian lake receiving uranium mill effluents were 7–11 times higher than those from fish caught in uncontaminated lakes.<sup>40</sup> Other dietary components that contribute to the daily intake of uranium are fresh vegetables and cereals. The predominant uranium isotope in food is <sup>238</sup>U.<sup>41</sup> Levels of <sup>234</sup>U and <sup>238</sup>U ranging from <1 to 220 mBq/L and from <2 to 740 mBq/L (0.2–60 µg/L), respectively, were reported in bottled waters in the Federal Republic of Germany.<sup>12</sup> In a study by Cheng *et al.*,<sup>42</sup> the mean uranium concentration in nine different beverages was 0.98 µg/L (range 0.26–1.65 µg/L), and the mean concentration of uranium in mineral water was 9.2 µg/L.

The average daily per capita intake of uranium in food has been reported to be 1.3 µg<sup>41</sup> and 2–3 µg<sup>43</sup> in the United States and 1.5 µg in Japan.<sup>38</sup> In a review of naturally occurring sources of radioactive contamination in food, dietary intakes of <sup>238</sup>U were found to range from 1.0 to 3.6 µg/d (12–45 mBq/d) in several European countries, from 0.9 to 4.8 µg/d (11–60 mBq/d) in Japan (the higher values were found in uranium mining areas) and from 1.2 to 1.4 µg/d (15–17 mBq/d) in the United States. The average daily dietary intake was of the order of 20 mBq, or about 1.6 µg. It was often difficult to

determine whether these dietary intakes included that from drinking water, and it was emphasized that the latter has sometimes been found to be equal to that from the diet.<sup>44</sup>

Mean levels of uranium in ambient air have been reported to be 0.02 ng/m<sup>3</sup> in Tokyo (based on a 1979–81 survey)<sup>45</sup> and 0.076 ng/m<sup>3</sup> in New York (based on two samples, each a composite of two weekly air filter collections, from 1985 and 1986).<sup>41</sup> Tracy and Prantl<sup>16</sup> found the average concentration of uranium in air in a southern Ontario rural environment to be 0.1 ng/m<sup>3</sup>, based on measurements of <sup>226</sup>Ra in dust and an assumption of equilibrium between <sup>238</sup>U and <sup>226</sup>Ra. Assuming a daily respiratory volume of 20 m<sup>3</sup> and a mean urban airborne level of 0.05 ng/m<sup>3</sup>, the daily intake of uranium from air would be about 1.0 ng. Tobacco smoke (from two packages of cigarettes per day) contributes less than 0.05 µg of inhaled uranium per day.<sup>47</sup>

The daily intake of uranium from each source for adults is thus estimated to be: air, 0.001 µg; food, 2.0 µg; water, 0.6 µg. Thus, the total daily intake is approximately 2.6 µg, or 0.037 µg/kg bw for a 70-kg adult; the majority (77%) originates from food, whereas drinking water contributes most of the remainder. This is in general agreement with a review of available data for the U.S. Environmental Protection Agency, which suggested that the mean contribution of uranium from drinking water to total intake is 31.1%.<sup>35,36</sup> The potential for uranium exposure will be greater for individuals who consume foods grown in areas with elevated concentrations of uranium in the soil and for individuals who consume drinking water containing elevated concentrations of uranium.<sup>48</sup> In a Canadian study, Limson Zamora *et al.*<sup>49</sup> found that water contributed between 31 and 98% of total daily uranium intake from food and water for individuals whose drinking water contained uranium at concentrations ranging from 2 to 780 µg/L; in contrast, intake from water was only 1–9% of total uranium intake for individuals whose municipal drinking water supply contained uranium at a concentration of 0.02 ± 0.004 µg/L.

## Health Effects

### Absorption, Distribution and Excretion

Although ubiquitous in the environment, uranium has no known metabolic function in animals and is currently regarded as non-essential.<sup>3</sup>

Absorption of uranium from the gastrointestinal tract depends upon the solubility of the uranium compound,<sup>3</sup> previous food consumption,<sup>50,51</sup> dose<sup>51</sup> and the concomitant administration of oxidizing agents, such as the iron(III) ion and quinhydrone.<sup>50</sup> The average gastrointestinal absorption of uranium in an adult human is 1–2%,<sup>52–54</sup> but uptake may be less than 0.1% or as high

as 5–6% under some conditions.<sup>55</sup> Tracy and Limson Zamora,<sup>56</sup> in a study of 60 volunteers, reported a geometric mean gastrointestinal uptake of 1%, with a variation from 0.1 to 4%. Only 0.06% of ingested uranium was absorbed in Sprague-Dawley rats and New Zealand white rabbits fed *ad libitum* and provided free access to drinking water containing uranyl nitrate hexahydrate at concentrations up to 600 mg/L for periods up to 91 days.<sup>57</sup>

Following ingestion, uranium rapidly appears in the bloodstream,<sup>51</sup> where it is associated primarily with the red cells<sup>58</sup>; in the plasma, a non-diffusible uranyl-albumin complex is formed in equilibrium with a diffusible ionic uranyl hydrogen carbonate complex (UO<sub>2</sub>HCO<sub>3</sub><sup>+</sup>).<sup>25</sup> Because of their high affinity for phosphate, carboxyl and hydroxyl groups, uranyl compounds readily combine with proteins and nucleotides to form stable complexes.<sup>25</sup> Clearance from the bloodstream is also rapid, and the uranium subsequently accumulates in the kidneys and the skeleton; little is found in the liver.<sup>51</sup> In the skeleton, which is the major site of uranium accumulation,<sup>52</sup> the uranyl ion replaces calcium in the hydroxyapatite complex of bone crystals.<sup>25</sup>

Based on the results of studies in experimental animals, it appears that the amount of soluble uranium accumulated internally is proportional to the intake from ingestion or inhalation.<sup>52</sup> It has been estimated that the total body burden of uranium in humans is 40 µg.<sup>52,59</sup>

Once equilibrium is attained in the skeleton, uranium is excreted in the urine and faeces. Urinary excretion in humans has been found to account for approximately 1% of total excretion, averaging 4.4 µg/d,<sup>43</sup> the rate depending in part on the pH of tubular urine.<sup>3</sup> Under alkaline conditions, most of the uranyl hydrogen carbonate complex is stable and is excreted in the urine. If the pH is low, the complex dissociates to a variable degree, and the uranyl ion may then bind to cellular proteins in the tubular wall. This results in reduced uranyl ion excretion, and the protein binding can impair tubular function.

The half-life of uranium in the rat kidney has been estimated to be approximately 15 days. Clearance from the skeleton is considerably slower; half-lives of 300 and 5000 days have been estimated, based on a two-compartment model.<sup>52</sup> Overall half-lives for the clearance of uranium from the rat kidney and skeleton of 5–11 and 93–165 days, respectively, were determined in another study, based on a 10-compartment model.<sup>60</sup> The overall elimination half-life of uranium under conditions of normal daily intake has been estimated to be between 180 and 360 days.<sup>3</sup> For rabbits, Tracy *et al.*<sup>57</sup> found uranium half-lives of 14 days in kidney and greater than 200 days in bone. Fourteen percent of absorbed uranium was deposited in bone, and 3% in kidney.

### Effects in Humans

Nephritis is the primary chemically induced effect of uranium in animals and humans.<sup>61</sup>

Little information is available on the chronic health effects of exposure to environmental uranium in humans. In Nova Scotia, clinical studies were performed upon 324 persons exposed to variable amounts of naturally occurring uranium in their drinking water (uranium concentrations up to 0.7 mg/L), which was supplied from private wells. No relationship was found between overt renal disease or any other symptomatic complaint and exposure to uranium. However, a trend towards increasing excretion of urinary  $\beta_2$ -microglobulin with increasing concentration of uranium in well water was observed; this raises the possibility that an early tubular defect was present and suggests that this parameter might be useful as an index of subclinical toxicity. The group with the highest uranium concentration in well water failed to follow this trend, but this was attributed to the fact that most of the individuals in this group had significantly reduced their consumption of well water by the time the measurements were made, leading to the conclusion that the suspected tubular defect might well be rapidly reversible.<sup>24,25</sup>

In a study to determine renal effects induced by the chronic ingestion of uranium in drinking water, Limson Zamora *et al.*<sup>49</sup> divided residents from two communities (Nova Scotia and Ontario) into two groups: the high-exposure group ( $n = 30$ ) consumed drinking water that came from private wells and contained uranium concentrations of 2–781  $\mu\text{g/L}$ , whereas the low-exposure group ( $n = 20$ ) drank water that was supplied through the municipal distribution system and contained uranium at levels of  $\leq 1 \mu\text{g/L}$ . Total uranium intake from both water and food over a 3-day period was used as the indicator for establishing a correlation between uranium exposure and different biomarkers. Two types of biomarkers were used: indicators of kidney function (i.e., creatinine, glucose, total protein and  $\beta_2$ -microglobulin) and markers for cell toxicity (e.g., alkaline phosphatase,  $\gamma$ -glutamyl transferase and lactate dehydrogenase). Glucose excretion increased with increasing daily uranium intake, but creatinine and protein excretion did not; as well, alkaline phosphatase and  $\beta_2$ -microglobulin were positively correlated with uranium intake for pooled male and female data. Taken together, these results suggest that, at the levels of uranium intake observed in this study, the segment of the nephron most at risk to injury is the proximal tubule, rather than the glomerulus.

In a pilot study conducted in 1993 in three communities in Saskatchewan, there was a statistically significant association ( $p = 0.03$ ) between increasing but normal levels of urine albumin (measured as mg/mmol creatinine) and the uranium cumulative index. According to the authors, microalbuminuria has been shown to be a sensitive indicator of early renal disease. The

cumulative index was calculated for each study participant as the product of the uranium concentration in drinking water, the number of cups of water consumed per day and the number of years lived at the current residence.<sup>62</sup> The study was conducted with 100 participants in three different areas with mean uranium levels ranging from 0.71 (control) to 19.6  $\mu\text{g/L}$ . Urine albumin levels ranged from 0.165 to 16.1 mg/mmol creatinine, with eight participants having "elevated" urine albumin concentrations ( $>3.0 \text{ mg/mmol creatinine}$ ). Three participants had serum creatinine concentrations of  $>120 \mu\text{mol/L}$  (range 50–170  $\mu\text{mol/L}$ ), which is indicative of prevalent renal damage. There is no reason to believe that these elevated creatinine values are due to uranium ingestion. It should be noted, however, that diabetics were not excluded from the study, although diabetic status and age, known risk factors for renal dysfunction, were factored into the statistical analysis of the results. A follow-up study is currently in progress.

### Toxicological Studies

Reported oral  $\text{LD}_{50}$ s of uranyl acetate for rats and mice are 204 mg/kg bw and 242 mg/kg bw, respectively.<sup>63</sup> Among the most common signs of acute toxicity are piloerection, significant weight loss and haemorrhages in the eyes, legs and nose.

The most common renal injury caused by uranium in experimental animals is damage to the proximal convoluted tubules, predominantly in the distal two-thirds<sup>3,64,65</sup>; the rate at which the effects occur varies with dosage level.<sup>66</sup> It has recently been shown that uranyl inhibits both  $\text{Na}^+$  transport-dependent and  $\text{Na}^+$  transport-independent ATP utilization as well as mitochondrial oxidative phosphorylation in the renal proximal tubule.<sup>65,66</sup> At doses not high enough to destroy a critical mass of kidney cells, the effect appears to be reversible, as some of the cells are replaced; however, the new epithelial lining differs morphologically, and possibly functionally, from normal epithelium.<sup>3,52</sup> Histopathologically, the regenerated cells are simple flattened cells with no microvilli on luminal surfaces and with reduced numbers of mitochondria.<sup>66</sup>

There is some evidence that tolerance may develop following repeated exposure to uranium.<sup>67–69</sup> This tolerance does not, however, prevent chronic damage to the kidney, as the regenerated cells are quite different; although histopathologically it may appear that the repair process is well advanced, the urinary biochemical changes return to normal only slowly.<sup>66</sup> Alterations causing thickening of the glomerular basement membrane of the kidney, which results from the storage of uranium in the kidney, can be prolonged and severe enough to cause permanent damage.<sup>70</sup> Persistent ultrastructural changes in the proximal tubules of rabbits have also been reported to be associated with the kidney's ability to store uranium.<sup>71</sup> Cell damage in the

proximal tubules was significantly more severe in animals allowed up to a 91-day recovery period than in animals killed at the end of the exposure period. Acquired tolerance should therefore not be considered as a practical method of protection against uranium intoxication.

Forty male Sprague-Dawley rats given uranyl ethanoate dihydrate at 0, 2, 4, 8 or 16 mg/kg bw per day (equivalent to uranium doses of 0, 1.1, 2.2, 4.5 or 9.0 mg/kg bw per day) in drinking water for 4 weeks exhibited a variety of biochemical effects, including increases in blood glucose levels at  $\geq 4$  mg uranyl ethanoate dihydrate/kg bw per day, decreases in aspartate aminotransferase and alanine aminotransferase levels at  $\geq 8$  mg uranyl ethanoate dihydrate/kg bw per day, increases in several other haematological parameters at 16 mg uranyl ethanoate dihydrate/kg bw per day and increases in total protein levels in all treated groups.<sup>72</sup> The authors considered the no-observed-adverse-effect level (NOAEL) to be 2 mg uranyl ethanoate dihydrate/kg bw per day (1.1 mg U/kg bw per day).

Groups of 15 male and 15 female weanling Sprague-Dawley rats consumed water containing uranyl nitrate hexahydrate at <0.001 (control), 0.96, 4.8, 24, 120 or 600 mg/L (equivalent to uranium doses of <0.0001, 0.06, 0.31, 1.52, 7.54 and 36.73 mg/kg bw per day in males and <0.0001, 0.09, 0.42, 2.01, 9.98 and 53.56 mg/kg bw per day in females) for 91 days.<sup>73</sup> Histopathological changes were observed mainly in the liver, thyroid and kidney. In the liver, treatment-related lesions were seen in both sexes at all doses and were generally non-specific nuclear and cytoplasmic changes. The thyroid lesions were not considered specific to the uranium treatment. The kidney was the most affected tissue. In males, statistically significant treatment-related kidney lesions (reported at all doses) included nuclear vesiculation, cytoplasmic vacuolation and tubular dilation. Other statistically significant lesions in males ( $\geq 4.8$  mg uranyl nitrate hexahydrate/L) included glomerular adhesions, apical displacement of the proximal tubular epithelial nuclei and cytoplasmic degranulation. In females, statistically significant changes in the kidney included nuclear vesiculation of the tubular epithelial nuclei (all doses) and anisokaryosis (all doses except 4.8 mg uranyl nitrate hexahydrate/L). However, the most important changes in the female were the capsular sclerosis of glomeruli and reticulin sclerosis of the interstitial membranes; these changes occurred in all dose groups and are considered to be "nonreparable lesions." The lowest-observed-adverse-effect level (LOAEL) for adverse effects on the kidney of male and female rats, based on the frequency of degree of degenerative lesions in the renal proximal convoluted tubule, was considered to be 0.96 mg uranyl nitrate hexahydrate/L (equivalent to 0.09 mg U/kg bw per day in females and 0.06 mg U/kg bw per day in males). The reason for the difference

in sensitivity between males and females is not clear, but it did not appear to be due to differences in pharmacokinetics, as accumulation of uranium in renal tissue did not differ significantly between the two sexes at all doses and females received a larger time-weighted average dose than males.

In a similar study, groups of 10 male New Zealand white rabbits were given uranyl nitrate hexahydrate in drinking water at concentrations of <0.001 (controls), 0.96, 4.8, 24, 120 or 600 mg/L (determined to be equivalent to doses of 0, 0.05, 0.2, 0.88, 4.82 and 28.7 mg U/kg bw per day) for 91 days.<sup>74</sup> These rabbits were not *Pasteurella*-free, and four of them contracted a *Pasteurella* infection during the course of the study. In the same study, 10 *Pasteurella*-free female rabbits were exposed to drinking water containing <0.001 (controls), 4.8, 24 or 600 mg uranyl nitrate hexahydrate/L (equivalent to doses of 0, 0.49, 1.32 and 43.02 mg U/kg bw per day) for 91 days. In both sexes, histopathological changes were observed in the kidney tubule, liver, thyroid and aorta. In male rabbits, histopathological findings were observed in the kidney tubules at doses above 0.96 mg uranyl nitrate hexahydrate/L. When compared with controls, significant treatment-related changes included cytoplasmic vacuolation, anisokaryosis, nuclear pyknosis and nuclear vesiculation; the incidence of nuclear vesiculation and anisokaryosis appeared to be dose-related, with nuclear vesiculation having the higher frequency and severity. Other treatment-related changes included tubular dilation, hyperchromicity, tubular atrophy, changes in the interstitium collagen and reticulin sclerosis. In total, 10 different morphological indicators of tubular injury were observed in the highest exposure group. The LOAEL, based on the nuclear changes in the kidney, was considered to be 0.96 mg uranyl nitrate hexahydrate/L (equivalent to 0.05 mg U/kg bw per day). In *Pasteurella*-free female rabbits, dose-related and treatment-related nuclear changes in the kidney tubule included anisokaryosis and vesiculation, which were significantly different from effects observed in controls at all doses. Other treatment-related changes in the kidney included cytoplasmic vacuolation, tubular atrophy and nuclear pyknosis. In general, histopathological changes in the kidney in females were generally less marked than in males. The LOAEL was considered to be 4.8 mg uranyl nitrate hexahydrate/L (equivalent to 0.49 mg U/kg bw per day). In both sexes, histopathological changes in the liver, thyroid and aorta were similar. In the liver, changes may have been treatment-related, although very mildly affected animals were seen in all groups, and changes in the thyroid were mild. Changes in the aorta were not dose-dependent. It should be noted that no similar aortic changes were observed in the 91-day uranyl nitrate hexahydrate studies in rats.<sup>73</sup> It is interesting to note, however, that even though the female rabbits consumed on average 65% more water than

the males and their average uranium intake was approximately 50% greater on a mg/kg bw per day basis, their average tissue levels were not similarly raised. The average kidney uranium level in females was 20% of that in males, whereas the average bone uranium level in females was 76% of that in males. The differences between the males and females, both qualitative and quantitative, suggest pharmacokinetic parameter differences, which contrasts with the findings in the rat study by the same authors.<sup>73</sup>

In an additional study to observe the reversibility of renal injury in *Pasteurella*-free male New Zealand white rabbits, groups of 5–8 animals were given <0.001 (control), 24 or 600 mg uranyl nitrate hexahydrate/L (equivalent to 0, 1.36 and 40.98 mg U/kg bw per day) in drinking water for 91 days, with a recovery period of up to 91 days.<sup>75</sup> Minor histopathological lesions were seen in the liver, thyroid and aorta. In the kidney, tubular injury with degenerative nuclear changes, cytoplasmic vacuolation and tubular dilation was observed in the high-dose group, which did not exhibit consistent resolution even after a 91-day recovery period. Although the severity of the histopathological changes at 600 mg uranyl nitrate hexahydrate/L did not increase between the 45-day and 91-day recovery groups, the continued prevalence of histopathological changes during this time suggests a self-sustaining injury. Also, the presence of sclerotic changes in the tubular basement membranes and renal interstitium persisted during the recovery period and most likely represents a permanent injury.<sup>70,71,75</sup> In general, the male rabbits did not respond as dramatically as those in the earlier study,<sup>74</sup> although the histopathological changes observed in this study were similar to those noted in the female rabbits of the previous study. Animals in this study consumed approximately 33% more uranium per day than the males in the previous study,<sup>74</sup> yet uranium residues in kidney tissue were 30% less, which would appear to indicate that *Pasteurella*-free rabbits are less sensitive than the non-*Pasteurella*-free strain to the effects of the uranyl ion in drinking water. Based on the histopathological data in the kidney, a LOAEL for the male New Zealand rabbits in this study is estimated to lie at or below 24 mg uranyl nitrate hexahydrate/L.

In an early series of experiments, very high doses (up to 20% in the diet) of a variety of uranium compounds were fed to rats, dogs and rabbits for periods ranging from 30 days to 2 years.<sup>76</sup> On the basis of very limited histopathological investigations, renal damage was reported in each species.

Adverse reproductive effects, in terms of total number of litters and average number of young per litter, were reported in rats given 2% uranyl nitrate hexahydrate for 7 months.<sup>76</sup> More recent studies have examined the teratogenic/embryotoxic effects and reproductive outcomes of uranyl acetate dihydrate administration to

mice. Domingo *et al.*<sup>77</sup> evaluated the developmental toxicity of uranium by treating groups of 20 pregnant Swiss mice by gavage to doses of 0, 5, 10, 25 or 50 mg uranyl acetate dihydrate/kg bw per day (equivalent to 0, 2.8, 5.6, 14 and 28 mg U/kg bw per day) on days 6–15 of gestation; the animals were sacrificed on day 18. Although all dams survived, there was a dose-related reduction in maternal weight gain, a significant decrease in daily feed intake and a significant increase in liver weights. Exposure-related foetotoxicity, including reduced foetal body weights and length, increased incidence of stunted foetuses per litter, increased incidence of both external and internal malformations and increased incidence of developmental variations, was observed in the foetuses of mice at all doses. At doses of  $\geq 14$  mg U/kg bw per day, specific malformations included cleft palate and bipartite sternebrae, and developmental variations included reduced ossification and unossified skeletal variations. There was no evidence of embryolethality at any dose. Based on both the maternal and foetotoxic effects, a LOAEL of 2.8 mg U/kg bw per day could be considered.

A second study by Domingo *et al.*<sup>78</sup> evaluated the effect of uranium on late foetal development, parturition, lactation and postnatal viability. Groups of 20 female mice were treated by gavage from day 13 of pregnancy until day 21 of lactation to doses of 0, 0.05, 0.5, 5 or 50 mg uranyl acetate dihydrate/kg bw per day (equivalent to 0, 0.028, 0.28, 2.8 and 28 mg U/kg bw per day). Maternal deaths (2/20 and 3/20 at the two highest doses, respectively) were attributed to the treatment; however, maternal toxicity was not evident from changes in body weight or food consumption, although relative liver weight was significantly reduced in all treatment groups. Decreases in pup viability, as indicated by significant decreases in litter size on day 21 of lactation, and significant decreases in the viability and lactation indexes were observed in the highest dose group. Based on developmental effects in pups, the authors established a no-observed-effect level (NOEL) of 2.8 mg U/kg bw per day.

Paternain *et al.*<sup>79</sup> studied the effects of uranium on reproduction, gestation and postnatal survival in mice. Groups of 25 mature male Swiss mice were administered intragastric doses of 0, 5, 10 or 25 mg uranyl acetate dihydrate/kg bw per day (equivalent to 0, 2.8, 5.6 and 14 mg U/kg bw per day) for 60 days prior to mating with mature females (25 per group). Females were exposed for 14 days prior to mating (males and females were mated according to their respective dose levels), and exposure continued through mating, gestation, parturition and nursing of litters; half the treated dams were sacrificed on day 13 of gestation. No treatment-related effects on mating or fertility were observed. Embryolethality (number of late resorptions and dead foetuses) was significantly increased and the number of live

foetuses was decreased in the highest dose group. Lethality in pups (at birth and at day 4 of lactation) was significantly increased at  $\geq 5.6$  mg U/kg bw per day, and pup growth (decreases in weight and length) and development of offspring, from birth and during the entire lactation period, were significantly affected in the high-dose group. The NOEL was 5 mg uranyl acetate dihydrate/kg bw per day, equivalent to 2.8 mg U/kg bw per day.

Unspecified degenerative changes in the testes of rats have also been reported following chronic administration of uranyl nitrate hexahydrate and uranyl fluoride in the diet.<sup>76,80,81</sup> In a more recent study, male Swiss mice were exposed for 64 days to uranyl acetate dihydrate in drinking water at doses of 0, 10, 20, 40 or 80 mg/kg bw per day (equivalent to 0, 5.6, 11.2, 22.4 and 44.8 mg U/kg bw per day) prior to mating with untreated females for 4 days.<sup>82</sup> With the exception of interstitial alterations and vacuolization of Leydig cells at the highest dose, no effects were observed in testicular function/spermatogenesis. There was, however, a significant, non-dose-related decrease in the pregnancy rate of these animals.

Although bone cancer has been induced in experimental animals by injection or inhalation of soluble compounds of high-specific-activity uranium isotopes or mixtures of uranium isotopes, no carcinogenic effects have been reported in animals ingesting soluble or insoluble uranium compounds.<sup>52</sup>

#### Mutagenicity

Uranyl nitrate was cytotoxic and genotoxic in Chinese hamster ovary cells at concentrations ranging from 0.01 to 0.3 mmol/L. There was a dose-related decrease in the viability of the cells, a decrease in cell cycle kinetics and increased frequencies of micronuclei, sister chromatid exchanges and chromosomal aberrations.<sup>83</sup> The authors suggest that the data provide a possible mechanism for the teratogenic effects observed in the studies by Domingo *et al.*<sup>77</sup> The genotoxic effects in this study were thought to occur through the binding of the uranyl nitrate to the phosphate groups of DNA. Chromosomal aberrations have also been induced in male mouse germ cells exposed to enriched uranyl fluoride; however, these aberrations may have been produced by the radioactivity of the test compound.<sup>84</sup>

#### Other Special Studies

A number of studies have reported that the toxic effects of uranium can be prevented, or possibly alleviated, by the administration of chelating agents.<sup>65</sup> Three chelating agents have been found to be effective at enhancing faecal excretion of uranium and reducing levels of uranium in bone and kidney in mice — sodium 4,5-dihydroxybenzene-1,3-disulfonate (Tiron), desferrioxamine (DFOA) and 1,2-dimethyl-3-hydroxypyrid-

4-one (L1); Tiron was the most effective agent of the compounds studied. However, administration of these agents 24 hours or more after uranium exposure was not effective.

#### Classification and Assessment

Although the potential exists for radiological toxicity of orally administered <sup>235</sup>U, this has not been observed in humans or animals, presumably because of the relatively low specific activity of this mixture of uranium radionuclides. Experimental evidence of the carcinogenicity of uranium is restricted to highly insoluble or enriched uranium compounds delivered by inhalation or injection. Although these observations do not seem relevant to the ingestion of <sup>235</sup>U in drinking water,<sup>52</sup> the associated risk for induction of bone cancer has been inferred from the known risk due to <sup>226</sup>Ra exposure. The estimated excess risk of induction of bone sarcoma is considered to be insignificant compared with the normal background lifetime risk.<sup>52</sup> The chemical toxicity of <sup>235</sup>U has been observed in both humans and animals. Because the chemical data reviewed to date suggest a more stringent recommendation than those based upon available radiological criteria, it is recommended that the assessment of uranium toxicity in drinking water be based upon chemical criteria. Uranium has, therefore, been included in Group V (inadequate data for evaluation of carcinogenicity).

For compounds classified in Group V, the maximum acceptable concentration (MAC) is derived on the basis of the division of the NOAEL or LOAEL for the critical response (i.e., nephrotoxicity for uranium) in humans or an animal species by an appropriate uncertainty factor. As no adequate chronic study was identified, the tolerable daily intake (TDI) has been derived based on the results of the most extensive subchronic studies, in the most sensitive sex and species, conducted to date in which uranium was administered in drinking water.<sup>73</sup> In the 91-day study in rats, the LOAEL for degenerative lesions in the proximal convoluted tubule of the kidney in males was considered to be 0.96 mg uranyl nitrate hexahydrate/L, which is equivalent to 0.06 mg U/kg bw per day (or 60  $\mu$ g/kg bw per day). The TDI is derived as follows:

$$\text{TDI} = \frac{60 \mu\text{g/kg bw per day}}{100} = 0.6 \mu\text{g/kg bw per day}$$

where:

- 60  $\mu$ g/kg bw per day is the LOAEL for adverse effects on the kidney in male rats (the most sensitive sex and species) in a subchronic study<sup>73</sup> (male rabbits were also more sensitive to the renal effects of uranium than females), and

- 100 is the uncertainty factor ( $\times 10$  for intraspecies variation and  $\times 10$  for interspecies variation).\*

### Rationale

Based on the above TDI, a health-based guideline value (GV) may be determined as follows:

$$GV = \frac{0.6 \mu\text{g/kg bw per day} \times 70 \text{ kg bw} \times 0.35}{1.5 \text{ L/d}} \approx 10 \mu\text{g/L}$$

where:

- 0.6  $\mu\text{g/kg bw per day}$  is the TDI, as derived above,
- 70 kg bw is the average weight of an adult,
- 0.35 is the proportion of daily intake of uranium allocated to drinking water; this allocation factor was determined, from data in the "Exposure" section, to best describe intake for the general population, which is generally exposed to drinking water containing uranium at concentrations below 10  $\mu\text{g/L}$ ,
- 1.5 L/d is the average daily consumption of drinking water by an adult.

After due consideration of both the treatment costs associated with achieving uranium concentrations in drinking water at or below the health-based guideline value and the health risks associated with concentrations of uranium in drinking water above the guideline value, the Committee on Drinking Water has concluded that an interim maximum acceptable concentration (IMAC) of 20  $\mu\text{g/L}$  should be adopted. This value is considered to be an interim guideline value because it is the result of a risk management decision and exceeds the health-based guideline value.

This IMAC is supported by a probabilistic analysis using Monte Carlo simulation in which a distribution of body weights and consumption rates for five different age categories was used to generate a distribution of guideline values. In this analysis, it was assumed that food is the only other significant source of exposure to uranium aside from drinking water. Food intake data from a duplicate diet study in a Nova Scotia community that had high levels of uranium in the drinking water were used. A guideline value of 20  $\mu\text{g/L}$  was shown to be suitably protective of the bulk of the population, especially if one considers that the TDI is already conservative, since it is based on a sensitive outcome in a sensitive species, with large uncertainty factors applied.

The IMAC will be reviewed periodically in light of developments in treatment technology and additional data on health risks associated with exposure to uranium in drinking water.

\* There is no need to apply an additional uncertainty factor to account for the use of a LOAEL instead of a NOAEL because of the minimal degree of severity of the lesions being reported. Also, an additional uncertainty factor for the length of the study (91 days) is not required because the estimated half-life of uranium in the kidney is 15 days.

### References

1. Cothorn, C.R. and Lappenbuseh, W.L. Occurrence of uranium in drinking water in the US. *Health Phys.*, 45: 89-99 (1983).
2. Lide, D.R. (ed.). *Handbook of chemistry and physics*. CRC Press, Boca Raton, FL (1992-93).
3. Berlin, M. and Rudell, B. Uranium. In: *Handbook on the toxicology of metals*. 2nd edition. L. Friberg, G.F. Nordberg and V.B. Vouk (eds.). Elsevier Science Publishers, Amsterdam. pp. 623-637 (1986).
4. Roessler, C.E., Smith, Z.A., Bolch, W.E. and Prince, R.J. Uranium and radium-226 in Florida phosphate materials. *Health Phys.*, 37: 269 (1979).
5. Statistics Canada. *Canada yearbook — 1990*. Minister of Supply and Services Canada (1989).
6. Dreesen, D.R., Williams, J.M., Marple, M.L., Gladney, E.S. and Perrin, D.R. Mobility and bioavailability of uranium mill tailings constituents. *Environ. Sci. Technol.*, 16: 702-709 (1982).
7. Essien, I.O., Sandoval, D.N. and Kuroda, P.K. Deposition of excess amount of natural U from the atmosphere. *Health Phys.*, 48: 325-331 (1985).
8. Tadmor, J. Atmospheric release of volatilized species of radionuclides from coal-fired plants. *Health Phys.*, 50: 270-273 (1986).
9. Spalding, R.F. and Sackett, W.M. Uranium in runoff from the Gulf of Mexico distributive province: anomalous concentrations. *Science*, 175: 629-631 (1972).
10. Kreiger, H.L. and Whittaker, E.L. Prescribed procedures for measurement of radioactivity in drinking water. Report EPA-600/4-80-032, U.S. Environmental Protection Agency, Washington, DC (1980) [cited in Blanchard, R.L., Hahne, R.M.A., Kahn, B., McCurdy, D., Mellor, R.A., Moore, W.S., Sedlet, J. and Whittaker, E. Radiological sampling and analytical methods for national primary drinking water regulations. *Health Phys.*, 48(5): 587-600 (1985)].
11. Boomer, D.W. and Powell, M.J. Determination of uranium in environmental samples using inductively coupled plasma mass spectrometry. *Anal. Chem.*, 59: 2810-2813 (1987).
12. Gans, I. Natural radionuclides in mineral waters. *Sci. Total Environ.*, 45: 93-99 (1985).
13. Singh, N.P. and Wrenn, M.E. Determinations of actinides in biological and environmental samples. *Sci. Total Environ.*, 70: 187-203 (1988).
14. Brina, R. and Miller, A.G. Determination of uranium and lanthanides in real-world samples by kinetic phosphorescence analysis. *Spectroscopy*, 8: 25-31 (1993).
15. Jelinck, R.T. and Sorg, T.J. Operating a small full-scale ion exchange system for uranium removal. *J. Am. Water Works Assoc.*, July: 79-83 (1988).
16. Sorg, T.J. Methods for removing uranium from drinking water. *J. Am. Water Works Assoc.*, July: 105-111 (1988).
17. Lee, S.Y. and Bondietti, E.A. Methods of removing uranium from drinking water by metal hydroxides and anion exchange resin. *J. Am. Water Works Assoc.*, 75(10): 536-540 (1983).
18. Fox, K.R. and Sorg, T.J. Controlling arsenic, fluoride and uranium by point-of-use treatment. *J. Am. Water Works Assoc.*, 79(1): 81-84 (1987).
19. Huxstep, M.R. and Sorg, T.J. Reverse osmosis treatment to remove inorganic contaminants from water. Report EPA/600/52-87/109, U.S. Environmental Protection Agency, March (1987).
20. Sorg, T.J. Removal of uranium from drinking water by conventional treatment methods. In: *Radon, radium and uranium in drinking water*. C.R. Cothorn and P.A. Rebers (eds.). Lewis Publishers, Chelsea, MI. pp. 173-191 (1990).

21. Raff, O. and Wilken, R.D. Removal of dissolved uranium by nanofiltration. *Desalination*, 122(2-3): 147-150 (1999).
22. Vijayan, S. Personal communication. Waste Processing Technology Section, Health, Chemistry and Environment Division, Environmental Technologies Branch, Chalk River Laboratories, Atomic Energy of Canada Limited, Chalk River (2000).
23. Water Research Centre. Treatment technology for aluminium, boron and uranium. Document prepared for the World Health Organization by the Water Research Centre, Medmenham (1997).
24. Moss, M.A., McCurdy, R.F., Dooley, K.C., Givner, M.L., Dymond, L.C., Slayter, J.M. and Courneya, M.M. Uranium in drinking water — report on clinical studies in Nova Scotia. In: Chemical toxicology and clinical chemistry of metals. S.S. Brown and J. Savory (eds.). Academic Press, London. pp. 149-152 (1983).
25. Moss, M.A. Chronic low level uranium exposure via drinking water — clinical investigations in Nova Scotia. M.Sc. thesis. Dalhousie University, Halifax (1985).
26. Province of British Columbia. Variation in uranium and radioactivity levels in surface and ground water at selected sites in British Columbia, April 1980 – March 1981. B.C. Ministry of Energy, Mines and Petroleum Resources and B.C. Ministry of Health, Victoria (1981).
27. Betcher, R.N., Gascoyne, M. and Brown, D. Uranium in groundwaters of southeastern Manitoba, Canada. *Can. J. Earth Sci.*, 25: 2089-2103 (1988).
28. Meyerhof, D. Letter to D. Rocan, Manitoba Department of the Environment, from D. Meyerhof, Bureau of Radiation Protection, Environmental Radiation Hazards Division, Health Canada, re: "Radionuclide analyses of community well-waters in Manitoba," dated February 14 (1989).
29. Hunt, W. Personal communication. Radiation Protection Bureau, Environmental Radiation Hazards Division, Health Canada, Ottawa (1996).
30. Ontario Ministry of Environment and Energy. Monitoring data for uranium — 1990-1995. Ontario Drinking Water Surveillance Program, Toronto (1996).
31. Riopel, A. Memo to H. Tremblay, Ministère de l'Environnement et de la Faune du Québec, from A. Riopel, Service de l'assainissement des eaux et du traitement des eaux de consommation, Ministère de l'Environnement et de la Faune du Québec, re: "Résultats d'uranium," dated January 26 (1996).
32. Moore, J., Limson-Zamora, M., Whiteduck, L. and Schwartz, H.M. Elevated uranium levels in groundwater and the potential bioeffects. Presented at the 7th National Conference on Drinking Water, Charlottetown, August 10-13 (1996).
33. Thomas, N. Personal communication. Data provided by the New Brunswick Department of Health and Community Services, Fredericton (1997).
34. Grantham, D.A. The occurrence and significance of uranium, radium and radon in water supplies in Nova Scotia. A report of the investigation carried out by the provincial uranium task force. Department of Health, Province of Nova Scotia (1986).
35. U.S. Environmental Protection Agency. Occurrence and exposure assessment for uranium in public drinking water supplies. EPA Contract No. 68-03-3514, report prepared by Wade Miller Associates, Inc. for the Office of Drinking Water, April 26 (1990).
36. U.S. Environmental Protection Agency. Review of RSC [Relative Source Contribution] analysis. Report prepared by Wade Miller Associates, Inc. for the Office of Drinking Water, May 9 (1991) [follow-up to reference 35].
37. Fisenne, I.M. and Welford, G.A. Natural U concentration in soft tissues and bone of New York City residents. *Health Phys.*, 50(6): 739-746 (1986).
38. Nozaki, T., Ichikawa, M., Sasuga, T. and Inarida, M.J. Neutron activation analysis of uranium in human bone, drinking water and daily diet. *J. Radioanal. Chem.*, 6: 33-40 (1970).
39. Landa, E.R. and Councell, T.B. Leaching of uranium from glass and ceramic foodware and decorative items. *Health Phys.*, 63: 343-348 (1992).
40. Swanson, S.M. Food chain transfer of U-series radionuclides in northern Saskatchewan aquatic system. *Health Phys.*, 49: 747-770 (1985).
41. Fisenne, I.M., Perry, P.M., Decker, K.M. and Keller, H.W. The daily intake of  $^{234}\text{U}$ ,  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{226}\text{Ra}$  and  $^{222}\text{Rn}$  by New York City residents. *Health Phys.*, 53: 357-363 (1987).
42. Cheng, Y.L., Lin, J.Y. and Hao, X.H. Trace uranium determination in beverages and mineral water using fission track techniques. *Nucl. Tracks Radiat. Meas.*, 22(1-4): 853-855 (1993).
43. Singh, N.P., Burleigh, D.P., Ruth, H.M. and Wrenn, M.E. Daily U intake in Utah residents from food and drinking water. *Health Phys.*, 59(3): 333-337 (1990).
44. Harley, J.H. Naturally occurring sources of radioactive contamination. In: Radionuclides in the food chain. J.H. Harley, G.D. Schmidt and G. Silini (eds.). Springer-Verlag, Berlin (1988).
45. Hirose, K. and Sugimura, Y. Concentration of uranium and the activity ratio of  $^{234}\text{U}/^{238}\text{U}$  in surface air: effect of atmospheric burn-up of Cosmos-954. *Meteorol. Geophys.*, 32: 317 (1981), cited in reference 37.
46. Tracy, B.L. and Prantl, F.A. Radiological impact of coal-fired power generation. *J. Environ. Radioactivity*, 2: 145-160 (1985).
47. Lucas, H.F. and Markun, F. Thorium and uranium in blood, urine and cigarettes. In: Argonne National Laboratory Radiation Physics Division Annual Report, Part 2. ANL-7760, Argonne National Laboratory, Argonne, IL. pp. 47-52 (1970).
48. Agency for Toxic Substances and Disease Registry. Draft toxicological profile for uranium. U.S. Department of Health and Human Services, Atlanta, GA (1997).
49. Limson Zamora, M., Tracy, B.L., Zielinski, J.M., Meyerhof, D.P. and Moss, M.A. Chronic ingestion of uranium in drinking water: a study of kidney bioeffects in humans. *Toxicol. Sci.* 43(1): 68-77 (1998).
50. Sullivan, M.F., Ruemmler, P.S., Ryan, J.L. and Buschborn, R.L. Influence of oxidizing or reducing agents on gastrointestinal absorption of U, Pu, Am, Cm, and Pm by rats. *Health Phys.*, 50(2): 223-232 (1986).
51. La Touche, Y.D., Willis, D.L. and Dawydiak, O.I. Absorption and biokinetics of U in rats following an oral administration of uranyl nitrate solution. *Health Phys.*, 53(2): 147-162 (1987).
52. Wrenn, M.E., Durbin, P.W., Howard, B., Lipsztein, J., Rundo, J., Still, E.T. and Willis, D.L. Metabolism of ingested U and Ra. *Health Phys.*, 48(5): 601-633 (1985).
53. Wrenn, M.E., Singh, N.P., Ruth, H., Rallison, M.L. and Burleigh, D.P. Gastrointestinal absorption of soluble uranium from drinking water by humans. In: Radon, radium and uranium in drinking water. C.R. Cothorn and P.A. Rebers (eds.). Lewis Publishers, Chelsea, MI. pp. 159-163 (1990).
54. Harduin, J.C., Royer, P. and Picchowski, J. Uptake and urinary excretion of uranium after oral administration in man. *Radiat. Prot. Dosim.*, 53(1-4): 245-248 (1994).
55. Leggett, R.W. and Harrison, J.D. Fractional absorption of ingested uranium in humans. *Health Phys.*, 68(4): 484-498 (1995).
56. Tracy, B.L. and Limson Zamora, M. Absorbed fraction of uranium in humans. Poster presentation, 39th Annual Meeting of the Health Physics Society, San Francisco, CA, June 26-30 (1994).

57. Tracy, B.L., Quinn, J.M., Lahey, J., Gilman, A.P., Mancuso, K., Yagminas, A.P. and Villeneuve, D.C. Absorption and retention of uranium from drinking water by rats and rabbits. *Health Phys.*, 62(1): 65-73 (1992).
58. Fisenne, I.M. and Perry, P.M. Isotopic U concentration in human blood from New York City donors. *Health Phys.*, 49(6): 1272-1275 (1985).
59. Igarashi, Y., Yamakawa, A. and Ikeda, N. Plutonium and uranium in Japanese human tissues. *Radioisotopes*, 36: 433-439 (1987).
60. Sontag, W. Multicompartment kinetic models for the metabolism of americium, plutonium and uranium in rats. *Hum. Toxicol.*, 5: 163-173 (1986).
61. Hursh, J.B. and Spoor, N.L. Data on man. In: *Handbook of experimental pharmacology*. Vol. 36. Uranium, plutonium, transplutonic elements. H.C. Hodge *et al.* (eds.). Springer-Verlag, Berlin. pp. 197-240 (1973).
62. Mao, Y., Desmeules, M., Schaubel, D., Bérubé, D., Dyck, R., Brûlé, D. and Thomas, B. Inorganic components of drinking water and microalbuminuria. *Environ. Res.*, 71: 135-140 (1995).
63. Domingo, J.L., Llobet, J.M., Tomás, J.M. and Corbella, J. Acute toxicity of uranium in rats and mice. *Bull. Environ. Contam. Toxicol.*, 39: 168-174 (1987).
64. Anthony, M.L., Gartland, K.P.R., Beddell, C.R., Lindon, J.C. and Nicholson, J.K. Studies of the biochemical toxicology of uranyl nitrate in the rat. *Arch. Toxicol.*, 68: 43-53 (1994).
65. Domingo, J.L. Chemical toxicity of uranium. *Toxicol. Ecotoxicol. News*, 2(3): 74-78 (1995).
66. Leggett, R.W. The behaviour and chemical toxicity of U in the kidney: a reassessment. *Health Phys.*, 57(3): 365-383 (1989).
67. Yuile, C.L. Animal experiments. In: *Handbook of experimental pharmacology*. Vol. 36. Uranium, plutonium, transplutonic elements. H.C. Hodge *et al.* (eds.). Springer-Verlag, Berlin. pp. 165-195 (1973).
68. Durbin, P.W. and Wrenn, M.E. Metabolism and effects of uranium in animals. In: *Conference on occupational health experience with uranium*. U.S. Energy Research and Development Administration, Washington, D.C. pp. 68-129 (1976) [available from U.S. National Technical Information Service].
69. Campbell, D.C.C. The development of an animal model with which to study the nephrotoxic effects of uranium-contaminated drinking water. M.Sc. thesis, Dalhousie University, Halifax (1985).
70. McDonald-Taylor, C.K., Bhatnagar, M.K. and Gilman, A. Uranyl nitrate-induced glomerular basement membrane alterations in rabbits: a quantitative analysis. *Bull. Environ. Contam. Toxicol.*, 48: 367-373 (1992).
71. McDonald-Taylor, C.K., Singh, A. and Gilman, A. Uranyl nitrate-induced proximal tubule alterations in rabbits: a quantitative analysis. *J. Toxicol. Pathol.*, 25(4): 381-389 (1997).
72. Ortega, A., Domingo, J.L., Llobet, J.M., Tomás, J.M. and Paternain, J.L. Evaluation of the oral toxicity of uranium in a 4-week drinking water study in rats. *Bull. Environ. Contam. Toxicol.*, 42: 935-941 (1989).
73. Gilman, A.P., Villeneuve, D.C., Secours, V.E., Yagminas, A.P., Tracy, B.L., Quinn, J.M., Valli, V.E., Willes, R.J. and Moss, M.A. Uranyl nitrate: 28-day and 91-day toxicity studies in the Sprague-Dawley rat. *Fundam. Appl. Toxicol.*, 41: 117-128 (1998).
74. Gilman, A.P., Villeneuve, D.C., Secours, V.E., Yagminas, A.P., Tracy, B.L., Quinn, J.M., Valli, V.E. and Moss, M.A. Uranyl nitrate: 91-day toxicity studies in the New Zealand white rabbit. *Fundam. Appl. Toxicol.*, 41: 129-137 (1998).
75. Gilman, A.P., Moss, M.A., Villeneuve, D.C., Secours, V.E., Yagminas, A.P., Tracy, B.L., Quinn, J.M., Long, G. and Valli, V.E. Uranyl nitrate: 91-day exposure and recovery studies in the male New Zealand white rabbit. *Fundam. Appl. Toxicol.*, 41: 138-151 (1998).
76. Maynard, E.A. and Hodge, H.C. Studies of the toxicity of various uranium compounds when fed to experimental animals. In: *Pharmacology and toxicology of uranium compounds*. C. Voegtlin (ed.). McGraw-Hill, New York, NY. pp. 309-376 (1949).
77. Domingo, J.L., Paternain, J.L., Llobet, J.M. and Corbella, J. The developmental toxicity of uranium in mice. *Toxicology*, 55(1-2): 143-152 (1989).
78. Domingo, J.L., Ortega, A., Paternain, J.L. and Corbella, J. Evaluation of the perinatal and postnatal effects of uranium in mice upon oral administration. *Arch. Environ. Health*, 44(6): 395-398 (1989).
79. Paternain, J.L., Domingo, J.L., Ortega, A. and Llobet, J.M. The effects of uranium on reproduction, gestation, and postnatal survival in mice. *Ecotoxicol. Environ. Saf.*, 17: 291-296 (1989).
80. Maynard, E.A., Downs, W.L. and Hodge, H.C. Oral toxicity of uranium compounds. In: *Pharmacology and toxicology of uranium compounds*. C. Voegtlin and H.C. Hodge (eds.). *Chronic inhalation and other studies*. McGraw-Hill, New York, NY. pp. 1121-1369 (1953).
81. Malenchenko, A.F., Barkun, N.A. and Guseva, G.F. Effect of uranium on the induction and course of experimental autoimmune ophthalmitis and thyroiditis. *J. Hyg. Epidemiol. Microbiol. Immunol.*, 22(3): 268-277 (1978).
82. Llobet, J.M., Sirvent, J.J., Ortega, A. and Domingo, J.L. Influence of chronic exposure to uranium on male reproduction in mice. *Fundam. Appl. Toxicol.*, 16: 821-829 (1991).
83. Lin, R.H., Wu, L.J., Lee, C.H. and Lin-Shiau, S.Y. Cytogenetic toxicity of uranyl nitrate in Chinese hamster ovary cells. *Mutat. Res.*, 319: 197-203 (1993).
84. Hu, Q. and Zhu, S. Induction of chromosomal aberrations in male mouse germ cells by uranyl fluoride containing enriched uranium. *Mutat. Res.*, 244: 209-214 (1990).

# EXHIBIT M

WHO/EOS/98.1  
Distribution: General  
English Only

# Guidelines for drinking-water quality

SECOND EDITION

*Addendum to Volume 2*

*Health criteria and  
other supporting information*

WA 675 W927  
v.2 Addendum 1998  
World Health Organization  
Guidelines for  
drinking-water quality

World Health Organization  
Geneva  
1998

THE UNIVERSITY OF NEW MEXICO  
HEALTH SCIENCES CENTER LIBRARY  
ALBUQUERQUE, NEW MEXICO 87131-5686



- Til HP et al. (1988) Evaluation of the oral toxicity of potassium nitrite in a 13-week drinking-water study in rats. *Food chemistry and toxicology*, 26(10):851-859.
- US EPA (1987) *Estimated national occurrence and exposure to nitrate and nitrite in public drinking water supplies*. Washington, DC, US Environmental Protection Agency, Office of Drinking Water.
- US National Research Council (1995) *Nitrate and nitrite in drinking water*. Subcommittee on Nitrate and Nitrite in Drinking Water, Committee on Toxicology, Board on Environmental Studies and Toxicology, Commission on Life Science. Washington, DC, National Academy Press.
- van Duijvenboden W, Loch JPG (1983) Nitrate in the Netherlands: a serious threat to groundwater. *Aqua*, 2:59-60.
- van Duijvenboden W, Matthijssen AJCM (1989) *Integrated criteria document nitrate*. Bilthoven, Rijksinstituut voor de Volksgezondheid en Milieuhygiëne (National Institute of Public Health and Environmental Protection) (RIVM Report No. 758473012).
- van Maanen JM et al. (1994) Consumption of drinking water with high nitrate levels causes hypertrophy of the thyroid. *Toxicology letters*, 72:365-374.
- Violante A, Cianetti A, Ordine A (1973) Studio della funzionella cortico surrenalica in corso di intossicazione con sodio nitrito. [Adrenal cortex function during subacute poisoning with sodium nitrite.] *Quaderni Sclavo di Diagnostica Clinica e di Laboratorio*, 9:907-920.
- Walker R (1995) The conversion of nitrate into nitrite in several animal species and man. In: *Health aspects of nitrate and its metabolites (particularly nitrite)*. Proceedings of an international workshop. Bilthoven (Netherlands), 8-10 November 1994. Strasbourg, Council of Europe Press, pp. 115-123.
- Walters CL, Smith PLR (1981) The effect of water-borne nitrate on salivary nitrite. *Food chemistry and toxicology*, 16:297-302.
- Walton G (1951) Survey of literature relating to infant methaemoglobinaemia due to nitrate-contaminated water. *American journal of public health*, 41:986-996.
- WHO (1985a) *Guidelines for the study of dietary intake of chemical contaminants*. Geneva, World Health Organization (WHO) (Offset Publication No. 87).
- WHO (1985b) *Health hazards from nitrate in drinking-water. Report on a WHO meeting, Copenhagen, 5-9 March 1984*. Copenhagen, WHO Regional Office for Europe (Environmental Health Series No. 1).
- WHO (1995) *Evaluation of certain food additives and contaminants*. Geneva, World Health Organization, Joint FAO/WHO Expert Committee on Food Additives, pp. 29-35 (WHO Technical Report Series No. 859).
- WHO (1996) *Toxicological evaluation of certain food additives and contaminants*. Prepared by the Forty-Fourth Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Geneva, World Health Organization, International Programme on Chemical Safety (WHO Food Additives Series 35).
- Wishnok JS et al. (1995) Endogenous formation of nitrate. In: *Health aspects of nitrate and its metabolites (particularly nitrite)*. Proceedings of an international workshop. Bilthoven (Netherlands), 8-10 November 1994. Strasbourg, Council of Europe Press, pp. 151-179.
- Wolf J (1994) Transport of iodide and other anions in the thyroid. *Physiology reviews*, 1:45-90.
- Wyngaarden JB, Stanbury JB, Rabb B (1953) The effects of iodide, perchlorate, thiocyanate, and nitrate administration upon iodide concentrating mechanism of the rat thyroid. *Endocrinology*, 52:568-574.
- Yocom JE (1982) Indoor/outdoor air quality relationships: a critical review. *Journal of the Air Pollution Control Association*, 32:500-606.
- Young CP, Morgan-Jones M (1980) A hydrogeochemical survey of the chalk groundwater of the Banstead area, Surrey, with particular reference to nitrate. *Journal of the Institute of Water Engineers and Scientists*, 34:213-236.

URANIUM<sup>1</sup>

First draft prepared by  
M. Giddings

Bureau of Chemical Hazards, Environmental Health Directorate  
Health Protection Branch, Health Canada, Ottawa, Ontario, Canada

At the time of publication of the 1993 *Guidelines for drinking-water quality*, adequate short- and long-term studies on the chemical toxicity of uranium were unavailable, and therefore a guideline value for uranium was not derived. Instead, it was recommended that the limits for radiological characteristics of uranium be adopted. The equivalent for natural uranium, based on these limits, is approximately 140 µg/litre.

As new data on the chemical toxicity of uranium are now available for use in the derivation of a guideline value, the 1995 Coordinating Committee for the Updating of WHO *Guidelines for drinking-water quality* recommended that uranium be included in the 1998 Addendum.

## 1. GENERAL DESCRIPTION

## 1.1 Identity

Uranium occurs naturally in the +2, +3, +4, +5, and +6 valence states, but it is most commonly found in the hexavalent form. In nature, hexavalent uranium is commonly associated with oxygen as the uranyl ion,  $UO_2^{2+}$ . Naturally occurring uranium (<sup>nat</sup>U) is a mixture of three radionuclides (<sup>234</sup>U, <sup>235</sup>U, and <sup>238</sup>U), all of which decay by both alpha and gamma emissions (Cothorn & Lappenbusch, 1983; Lide, 1992-93). Natural uranium consists almost entirely of the <sup>238</sup>U isotope, with the <sup>235</sup>U and <sup>234</sup>U isotopes respectively comprising about 0.72% and 0.0054% of natural uranium (Greenwood & Earnshaw, 1984). Uranium is widespread in nature, occurring in granites and various other mineral deposits (Roessler et al., 1979; Lide, 1992-93).

Compound	CAS no.	Molecular formula
Uranium	7440-61-1	U
Uranyl ethanoate	541-09-3	C <sub>2</sub> H <sub>4</sub> O <sub>6</sub> U
Uranyl chloride	7791-26-6	Cl <sub>2</sub> O <sub>2</sub> U
Uranyl nitrate	36478-76-9	N <sub>2</sub> O <sub>2</sub> U
Uranium dioxide	1344-57-6	UO <sub>2</sub>

<sup>1</sup> This review addresses only the chemical aspects of uranium toxicity. Information pertinent to the derivation of a guideline based on radiological effects is presented in the second edition of the *Guidelines for drinking-water quality*.

## 82 INORGANIC CONSTITUENTS

## 1.2 Physicochemical properties (Lide, 1992-93)

Compound	Melting point (°C)	Boiling point (°C)	Density at 20°C (g/cm <sup>3</sup> )	Water solubility (g/litre)
U	1132	3818	19.0	insoluble
C <sub>4</sub> H <sub>8</sub> O <sub>4</sub> U	110	275 (decomposes)	2.9	76.94
Cl <sub>2</sub> O <sub>2</sub> U	578	(decomposes)	-	3200
N <sub>2</sub> O <sub>5</sub> U	60.2	118	2.8	soluble
UO <sub>2</sub>	2878	-	10.96	insoluble

## 1.3 Major uses

Uranium is used mainly as fuel in nuclear power stations, although some uranium compounds are also used as catalysts and staining pigments (Berlin & Rudell, 1986).

## 1.4 Environmental fate

Uranium is present in the environment as a result of leaching from natural deposits, release in mill tailings, emissions from the nuclear industry, the combustion of coal and other fuels, and the use of phosphate fertilizers that contain uranium.

## 2. ANALYTICAL METHODS

Uranium in water is most commonly measured by solid fluorimetry with either laser excitation or ultraviolet light following fusion of the sample with a pellet of carbonate and sodium fluoride (detection limit 0.1 µg/litre) (Kreiger & Whittaker, 1980). Sample preparation for this method is tedious, however, and there is interference from other metals. Uranium can also be determined by inductively coupled plasma mass spectrometry, which has the same detection limit (0.1 µg/litre) and a between-run precision of less than 6% (Boomer & Powell, 1987). Alpha-spectrometry has been used for the determination of uranium in bottled waters (Gans, 1985) and environmental media (Singh & Wrenn, 1988), although the recovery is often highly variable owing to the low specific activity of natural uranium (Singh & Wrenn, 1988).

## 3. ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

## 3.1 Air

Mean levels of uranium in ambient air have been reported to be 0.02 ng/m<sup>3</sup> in Tokyo (based on a 1979-1981 survey) (Hirose & Sugimura, 1981) and 0.076 ng/m<sup>3</sup>

in New York (based on two samples, each a composite of two weekly air filter collections, from 1985 and 1986) (Fisenne et al., 1987). On the assumption of a daily respiratory volume of 20 m<sup>3</sup> and a mean urban airborne concentration of 0.05 ng/m<sup>3</sup>, the daily intake of uranium from air would be about 1 ng. Tobacco smoke (from two packages of cigarettes per day) contributes less than 50 ng of inhaled uranium per day (Lucas & Markun, 1970).

## 3.2 Water

In a survey of 130 sites (approximately 3700 samples) in Ontario, Canada, conducted between 1990 and 1995, the mean of the average uranium concentrations (range 0.05-4.21 µg/litre; detection limit 0.05 µg/litre) in treated drinking-water was 0.40 µg/litre (OMEE, 1996). Uranium concentrations of up to 700 µg/litre have been found in private supplies in Canada (Muss et al., 1983; Muss, 1985). The mean concentration of uranium in drinking-water in New York City, USA, ranged from 0.03 to 0.08 µg/litre (Fisenne & Welford, 1986). A mean uranium concentration of 2.55 µg/litre was reported in drinking-water from 978 sites in the USA in the 1980s (US EPA, 1990, 1991). In five Japanese cities, the mean level in potable water supplies was 0.9 ng/litre (Nozaki et al., 1970).

The daily uranium intake from water in Finland has been estimated to be 2.1 µg (Kahlos & Asikainen, 1980). The daily intake from drinking-water in Salt Lake City, USA, is estimated to be 1.5 µg (Singh et al., 1990). On the basis of the results of the survey from Ontario (OMEE, 1996), the daily intake of uranium from drinking-water in Canada is estimated to be 0.8 µg.

## 3.3 Food

Uranium has been detected in a variety of foodstuffs. The highest concentrations are found in shellfish, and lower levels have been measured in fresh vegetables, cereals, and fish. The average per capita intake of uranium in food has been reported to be 1.3 µg/day (Fisenne et al., 1987) and 2-3 µg/day (Singh et al., 1990) in the USA and 1.5 µg/day in Japan (Nozaki et al., 1970).

In a review of naturally occurring sources of radioactive contamination in food, dietary intakes of <sup>238</sup>U were found to range from 12 to 45 mBq/day in several European countries, from 11 to 60 mBq/day in Japan (the higher values were found in uranium mining areas), and from 15 to 17 mBq/day in the USA. The average daily dietary intake was in the order of 20 mBq, or about 4 µg. It was often difficult to determine whether these dietary intakes included intake from drinking-water, and it was emphasized that intake from drinking-water has sometimes been found to be equal to intake from the diet (Harley, 1988).

In a study by Cheng et al. (1993), the mean uranium concentration in nine different beverages was 0.98 µg/litre (range 0.26-1.65 µg/litre), and the mean concentration of uranium in mineral water was 9.20 µg/litre.

Landa & Councell (1992) performed leaching studies to determine the quantity of uranium leaching from 33 glass items and two ceramic items in which uranium was used as a colouring agent. Uranium-bearing glasses leached a

maximum of 30 µg of uranium per litre, whereas the ceramic-glazed items released approximately 300 000 µg of uranium per litre.

### 3.4 Estimated total exposure and relative contribution of drinking-water

The daily intake of uranium from each source for adults is estimated to be: air, 0.001 µg; drinking-water, 0.8 µg; food, 1.4 µg. Thus, the total daily intake is approximately 2.2 µg, or 0.037 µg/kg of body weight for a 60-kg adult, the majority of which originates from food.

## 4. KINETICS AND METABOLISM IN LABORATORY ANIMALS AND HUMANS

Although ubiquitous in the environment, uranium has no known metabolic function in animals and is currently regarded as non-essential (Berlin & Rudell, 1986). Absorption of uranium from the gastrointestinal tract depends upon the solubility of the uranium compound (Berlin & Rudell, 1986), previous food consumption (Sullivan et al., 1986; La Touche et al., 1987), and the concomitant administration of oxidizing agents, such as the iron(III) ion and quinhydrone (Sullivan et al., 1986). The average human gastrointestinal absorption of uranium is 1-2% (Wrenn et al., 1985).

The absorption of a uranium dose of approximately 800 mg/kg of body weight in starved female Sprague-Dawley rats increased from 0.17 to 3.3% when iron(III) (190 mg/kg of body weight) was administered simultaneously (Sullivan et al., 1986). Absorption of uranium in starved rats administered doses of uranium by gavage was reported to increase with dose; the degree of absorption ranged from 0.06 to 2.8% for doses between 0.03 and 45 mg of uranium per kg of body weight (La Touche et al., 1987). Only 0.06% of ingested uranium was absorbed in Sprague-Dawley rats and New Zealand white rabbits fed *ad libitum* and having free access to drinking-water containing up to 600 mg of uranyl nitrate hexahydrate per litre for up to 91 days (Tracy et al., 1992).

Following ingestion, uranium rapidly appears in the bloodstream (La Touche et al., 1987), where it is associated primarily with the red cells (Fiscenne & Perry, 1985); a non-diffusible uranyl-albumin complex also forms in equilibrium with a diffusible ionic uranyl hydrogen carbonate complex ( $UO_2HCO_3^{+}$ ) in the plasma (Moss, 1985). Because of their high affinity for phosphate, carboxyl, and hydroxyl groups, uranyl compounds readily combine with proteins and nucleotides to form stable complexes (Moss, 1985). Clearance from the bloodstream is also rapid, and the uranium subsequently accumulates in the kidneys and the skeleton, whereas little is found in the liver (La Touche et al., 1987). The skeleton is the major site of uranium accumulation (Wrenn et al., 1985); the uranyl ion replaces calcium in the hydroxyapatite complex of bone crystals (Moss, 1985).

Based on the results of studies in experimental animals, it appears that the amount of soluble uranium accumulated internally is proportional to the intake from ingestion or inhalation. It has been estimated that the total body burden of uranium in humans is 40 µg, with approximately 40% of this being present in the muscles,

20% in the skeleton, and 10%, 4%, 1%, and 0.3% in the blood, lungs, liver, and kidneys, respectively (Igarashi et al., 1987).

Once equilibrium is attained in the skeleton, uranium is excreted in the urine and faeces. Urinary excretion in humans has been found to account for approximately 1% of total excretion, averaging 4.4 µg/day (Singh et al., 1990), the rate depending in part on the pH of tubular urine (Berlin & Rudell, 1986). Under alkaline conditions, most of the uranyl hydrogen carbonate complex is stable and is excreted in the urine. If the pH is low, the complex dissociates to a variable degree, and the uranyl ion may then bind to cellular proteins in the tubular wall, which may then impair tubular function.

The half-life of uranium in the rat kidney has been estimated to be approximately 15 days. Clearance from the skeleton is considerably slower; half-lives of 300 and 5000 days have been estimated, based on a two-compartment model (Wrenn et al., 1985). In another study using a 10-compartment model, overall half-lives for the clearance of uranium from the rat kidney and skeleton were determined to be 5-11 and 93-165 days, respectively (Sontag, 1986). The overall elimination half-life of uranium under conditions of normal daily intake has been estimated to be between 180 and 360 days (Berlin & Rudell, 1986).

## 5. EFFECTS ON EXPERIMENTAL ANIMALS AND IN VITRO TEST SYSTEMS

### 5.1 Acute exposure

Reported oral LD<sub>50</sub>s of uranyl ethanoate dihydrate for rats and mice are 204 and 242 mg/kg of body weight, respectively (Domingo et al., 1987). Among the most common signs of acute toxicity are piloerection, significant weight loss, and haemorrhages in the eyes, legs, and nose.

The most common renal injury caused by uranium in experimental animals is damage to the proximal convoluted tubules, predominantly in the distal two-thirds (Berlin & Rudell, 1986; Anthony et al., 1994; Domingo, 1995); the rate of effects varies with dosage level (Leggett, 1989). It has recently been shown that uranyl inhibits both Na<sup>+</sup> transport-dependent and Na<sup>+</sup> transport-independent ATP utilization as well as mitochondrial oxidative phosphorylation in the renal proximal tubule (Leggett, 1989; Domingo, 1995). At doses not high enough to destroy a critical mass of kidney cells, the effect appears to be reversible, as some of the cells are replaced; however, the new epithelial lining differs morphologically, and possibly functionally, from normal epithelium (Wrenn et al., 1985; Berlin & Rudell, 1986). Histopathologically, the regenerated cells are simple flattened cells with no microvilli on luminal surfaces and with reduced numbers of mitochondria (Leggett, 1989).

There is some evidence that tolerance may develop following repeated exposure to uranium (Yuile, 1973; Durbin & Wrenn, 1976; Campbell, 1985). This tolerance does not, however, prevent chronic damage to the kidney, as the regenerated cells are quite different; although histopathologically it may appear that the repair process is well advanced, the urinary biochemical changes return to normal only slowly (Leggett, 1989). Alterations causing thickening of the

glomerular basement membrane of the kidney, which results from the storage of uranium in the kidney, can be prolonged and severe enough to cause permanent damage (McDonald-Taylor et al., 1992). Persistent ultrastructural changes in the proximal tubules of rabbits have also been reported to be associated with the kidney's ability to store uranium (McDonald-Taylor et al., 1997). Cell damage in the proximal tubules was significantly more severe in animals allowed up to a 91-day recovery period than in animals in the no-recovery group.

### 5.2 Short-term exposure

Forty male Sprague-Dawley rats given 0, 2, 4, 8, or 16 mg of uranyl ethanoate dihydrate per kg of body weight per day (equivalent to doses of 0, 1.1, 2.2, 4.5, or 9.0 mg of uranium per kg of body weight per day) in drinking-water for 2 weeks exhibited a variety of biochemical effects, including increases in blood glucose levels at  $\geq 4$  mg of uranyl ethanoate dihydrate per kg of body weight per day, decreases in aspartate aminotransferase and alanine aminotransferase values at  $\geq 8$  mg of uranyl ethanoate dihydrate per kg of body weight per day, increases in several other haematological parameters at 16 mg of uranyl ethanoate dihydrate per kg of body weight per day, and increases in total protein levels in all treated groups (Ortega et al., 1989). The authors considered the NOAEL to be 2 mg of uranyl ethanoate dihydrate per kg of body weight per day (1.1 mg of uranium per kg of body weight per day).

Groups of 15 male and 15 female weanling Sprague-Dawley rats consumed water containing <0.001 (control), 0.96, 4.8, 24, 120, or 600 mg of uranyl nitrate hexahydrate per litre (equivalent to doses of <0.0001, 0.06, 0.31, 1.52, 7.54, and 36.73 mg of uranium per kg of body weight per day in males and <0.0001, 0.09, 0.42, 2.01, 9.98, and 53.56 mg of uranium per kg of body weight per day in females) for 91 days (Gilman et al., 1997a). Histopathological changes were observed mainly in the liver, thyroid, and kidney. In the liver, treatment-related lesions were seen in both sexes at all doses and were generally non-specific nuclear and cytoplasmic changes. The thyroid lesions were not considered specific to the uranium treatment. The kidney was the most affected tissue. In males, statistically significant treatment-related kidney lesions (reported at all doses) included nuclear vesiculation, cytoplasmic vacuolation, and tubular dilation. Other statistically significant lesions in males ( $\geq 4.8$  mg of uranyl nitrate hexahydrate per litre) included glomerular adhesions, apical displacement of the proximal tubular epithelial nuclei, and cytoplasmic degranulation. In females, statistically significant changes in the kidney included nuclear vesiculation of the tubular epithelial nuclei (all doses) and anisokaryosis (all doses except 4.8 mg of uranyl nitrate hexahydrate per litre). However, the most important changes in the female were the capsular sclerosis of glomeruli and reticulin sclerosis of the interstitial membranes; these changes occurred in all dose groups and are considered to be "nonreparable lesions." Significant treatment-related liver changes were also reported in hepatic nuclei and cytoplasm in both sexes at the lowest exposure level. The LOAEL for adverse effects on the kidney and liver of male and female rats, based on the frequency of degree of degenerative lesions in the renal proximal convoluted tubule, was

considered to be 0.96 mg of uranyl nitrate hexahydrate per litre (equivalent to 0.09 mg of uranium per kg of body weight per day in females and 0.06 mg of uranium per kg of body weight per day in males). The reason for the difference in sensitivity between males and females is not clear, but it did not appear to be due to differences in pharmacokinetics, as accumulation of uranium in renal tissue did not differ significantly between the two sexes at all doses.

In a similar study, groups of 10 male New Zealand white rabbits were given uranyl nitrate hexahydrate in drinking-water at concentrations of <0.001 (controls), 0.96, 4.8, 24, 120, or 600 mg/litre (determined to be equivalent to doses of 0, 0.05, 0.2, 0.88, 4.82, and 28.7 mg of uranium per kg of body weight per day) for 91 days (Gilman et al., 1997b). Histopathological changes were observed in the kidney tubule, liver, thyroid, and aorta. Histopathological findings were observed in the kidney tubules at doses above 0.96 mg of uranyl nitrate hexahydrate per litre. When compared with controls, significant treatment-related changes included cytoplasmic vacuolation, anisokaryosis, nuclear pyknosis, and nuclear vesiculation; the incidence of nuclear vesiculation and anisokaryosis appeared to be dose-related, with nuclear vesiculation having the higher frequency and severity. Other treatment-related changes included tubular dilatation, hyperchromicity, tubular atrophy, changes in the interstitium collagen, and reticulin sclerosis. In total, 11 different morphological indicators of tubular injury were observed in the highest exposure group. The LOAEL, based on the nuclear changes in the kidney, was considered to be 0.96 mg of uranyl nitrate hexahydrate per litre (equivalent to 0.05 mg of uranium per kg of body weight per day). It should be noted, however, that these rabbits were not *Pasteurella*-free, and four of them contracted a *Pasteurella* infection during the course of the study. In the same study, 10 *Pasteurella*-free female rabbits were exposed to drinking-water containing <0.001 (controls), 4.8, 24, or 600 mg of uranyl nitrate hexahydrate per litre (equivalent to doses of 0, 0.49, 1.32, and 43.02 mg of uranium per kg of body weight per day) for 91 days. Dose-related and treatment-related nuclear changes in the kidney tubule included anisokaryosis and vesiculation, which were significantly different from effects observed in controls at all doses. Other treatment-related changes in the kidney included cytoplasmic vacuolation, tubular atrophy, and nuclear pyknosis. In general, histopathological changes in the kidney in females were generally less marked than in males. The LOAEL was considered to be 4.8 mg of uranyl nitrate hexahydrate per litre (equivalent to 0.49 mg of uranium per kg of body weight per day). In both sexes, histopathological changes in the liver, thyroid, and aorta were similar. In the liver, changes may have been treatment-related, although very mildly affected animals were seen in all groups, and changes in the thyroid were mild. Changes in the aorta were not dose-dependent. It should be noted that no similar aortic changes were observed in the 91-day uranyl nitrate hexahydrate studies in rats (Gilman et al., 1997a). It is interesting to note, however, that even though the female rabbits consumed on average 65% more water than the males and their average uranium intake was approximately 50% greater on a mg/kg of body weight per day basis, their average tissue levels were not similarly raised. The differences between the males and females, both qualitative and quantitative, suggest pharmacokinetic parameter differences, which contrasts with the findings in the rat study by the same authors (Gilman et al., 1997a).

In an additional study to observe the reversibility of renal injury in *Pasteurella*-free male New Zealand white rabbits, groups of 5–8 animals were given <math>0.001</math> (control), 24, or 600 mg of uranyl nitrate hexahydrate per litre (equivalent to 0, 1.36, and 40.98 mg of uranium per kg of body weight per day) in drinking-water for 91 days, with a recovery period of up to 91 days (Gilman et al., 1997c). Minor histopathological lesions were seen in the liver, thyroid, and aorta. In the kidney, tubular injury with degenerative nuclear changes, cytoplasmic vacuolation, and tubular dilation was observed in the high-dose group, which did not exhibit consistent resolution even after a 91-day recovery period. In general, the male rabbits did not respond as dramatically as those in the earlier study (Gilman et al., 1997b), although the histopathological changes observed in this study were similar to those noted in the female rabbits of the previous study. Animals in this study consumed approximately 33% more uranium per day than the males in the previous study (Gilman et al., 1997b), yet uranium residues in kidney tissue were 30% less, which would appear to indicate that *Pasteurella*-free rabbits are less sensitive than the non-*Pasteurella*-free strain to the effects of the uranyl ion in drinking-water. Based on the histopathological data in the kidney, a LOAEL for the male New Zealand rabbits in this study is estimated to lie between 24 and 600 mg of uranyl nitrate hexahydrate per litre.

### 5.3 Long-term exposure

In an early series of experiments, very high doses (up to 20% in the diet) of a variety of uranium compounds were fed to rats, dogs, and rabbits for periods ranging from 30 days to 2 years (Maynard and Hodge, 1949). On the basis of very limited histopathological investigations, renal damage was reported in each species.

### 5.4 Reproductive and developmental toxicity

Adverse reproductive effects, in terms of total number of litters and average number of young per litter, were reported in rats given 2% uranyl nitrate hexahydrate for 7 months (Maynard & Hodge, 1949). More recent studies have examined the teratogenic/embryotoxic effects and reproductive outcomes of uranyl acetate dihydrate in Swiss albino mice. Domingo et al. (1989a) evaluated the developmental toxicity of uranium by treating groups of 20 pregnant Swiss mice by gavage to doses of 0, 5, 10, 25, or 50 mg of uranyl acetate dihydrate per kg of body weight per day (equivalent to 0, 2.8, 5.6, 14, and 28 mg of uranium per kg of body weight per day) on days 6–15 of gestation; the animals were sacrificed on day 18. Although all dams survived, there was a dose-related reduction in maternal weight gain, a significant decrease in daily feed intake, and a significant increase in liver weights. Exposure-related fetotoxicity, including reduced fetal body weights and length, increased incidence of stunted fetuses per litter, increased incidence of both external and internal malformations, and increased incidence of developmental variations, was observed in the fetuses of mice at  $\geq 2.8$  mg of uranium per kg of body weight per day. At doses  $\geq 14$  mg of uranium per kg of body weight per day, specific malformations included cleft palate and bipartite sternabrae, and developmental

variations included reduced ossification and unossified skeletal variations. There was no evidence of embryoletality at any dose. Based on both the maternal and fetotoxic effects, a LOAEL of 2.8 mg of uranium per kg of body weight per day could be considered.

A second study by Domingo et al. (1989b) evaluated the effect of uranium on late fetal development, parturition, lactation, and postnatal viability. Groups of 20 female mice were treated by gavage from day 13 of pregnancy until day 21 of lactation to doses of 0, 0.05, 0.5, 5, or 50 mg of uranyl acetate dihydrate per kg of body weight per day (equivalent to 0, 0.028, 0.28, 2.8, and 28 mg of uranium per kg of body weight per day). Maternal deaths (2/20 at 2.8 mg of uranium per kg of body weight per day, and 3/20 at 28 mg of uranium per kg of body weight per day) were attributed to the treatment; however, maternal toxicity was not evident from changes in body weight or food consumption, although relative liver weight was significantly reduced in all treatment groups. Decreases in pup viability, as indicated by significant decreases in litter size on day 21 of lactation, and significant decreases in the viability and lactation indexes were observed in the high-dose group. Based on developmental effects in pups, a NOEL of 2.8 mg of uranium per kg of body weight per day was established.

Paternain et al. (1989) studied the effects of uranium on reproduction, gestation, and postnatal survival in mice. Groups of 25 mature male Swiss mice were exposed to oral doses of 0, 5, 10, or 25 mg of uranyl acetate dihydrate per kg of body weight per day (equivalent to 0, 2.8, 5.6, and 14 mg of uranium per kg of body weight per day) for 60 days prior to mating with mature females (25 per group). Females were exposed for 14 days prior to mating, and exposure continued through mating, gestation, parturition, and nursing of litters; half the treated dams were sacrificed on day 13 of gestation. No treatment-related effects on mating or fertility were observed. Embryoletality (number of late resorptions and dead fetuses) was significantly increased and the number of live fetuses was decreased in the high-dose group. Lethality in pups (at birth and at day 4 of lactation) was significantly increased at  $\geq 5.6$  mg of uranium per kg of body weight per day, and pup growth (decreases in weight and length) and development of offspring, from birth and during the entire lactation period, were significantly affected in the high-dose group.

Unspecified degenerative changes in the testes of rats have also been reported following chronic administration of uranyl nitrate hexahydrate and uranyl fluoride in the diet (Maynard and Hodge, 1949; Maynard et al., 1953; Malenchenko et al., 1978). In a more recent study, male Swiss mice were exposed for 64 days to uranyl acetate dihydrate in drinking-water at doses of 0, 10, 20, 40, or 80 mg/kg of body weight per day (equivalent to 0, 5.6, 11.2, 22.4, and 44.8 mg of uranium per kg of body weight per day) prior to mating with untreated females for 4 days (Llobet et al., 1991). With the exception of interstitial alterations and vacuolization of Leydig cells at the highest dose, no effects were observed in testicular function/spermatogenesis. There was, however, a significant, non-dose-related decrease in the pregnancy rate of these animals.

### 5.5 Mutagenicity and related end-points

Uranyl nitrate was cytotoxic and genotoxic in Chinese hamster ovary cells at concentrations ranging from 0.01 to 0.3 nmol/litre. There was a dose-related decrease in the viability of the cells, a decrease in cell cycle kinetics, and increased frequencies of micronuclei, sister chromatid exchanges, and chromosomal aberrations (Lin et al., 1993). The authors suggest that the data provide a possible mechanism for the teratogenic effects observed in the studies by Domingo et al. (1989a). The genotoxic effects in this study were thought to occur through the binding of the uranyl nitrate to the phosphate groups of DNA. Chromosomal aberrations have also been induced in male mouse germ cells exposed to enriched uranyl fluoride; however, these aberrations may have been produced by the radioactivity of the test compound (Hu & Zhu, 1990).

### 5.6 Carcinogenicity

Although bone cancer has been induced in experimental animals by injection or inhalation of soluble compounds of high-specific-activity uranium isotopes or mixtures of uranium isotopes, no carcinogenic effects have been reported in animals ingesting soluble or insoluble uranium compounds (Wrenn et al., 1985).

## 6. EFFECTS ON HUMANS

Nephritis is the primary chemically induced effect of uranium in humans (Hursh & Spoor, 1973).

Little information is available on the chronic health effects of exposure to environmental uranium in humans. In Nova Scotia, Canada, clinical studies were performed on 324 persons exposed to variable amounts of naturally occurring uranium in drinking-water (up to 0.7 mg/litre) supplied from private wells. No relationship was found between overt renal disease or any other symptomatic complaint and exposure to uranium. However, a trend towards increasing excretion of urinary  $\beta_2$ -microglobulin and increasing concentration of uranium in well-water was observed; this raises the possibility that an early tubular defect was present and suggests that this parameter might be useful as an index of subclinical toxicity. The group with the highest uranium concentrations in well-water failed to follow this trend, but this was attributed to the fact that most of the individuals in this group had significantly reduced their consumption of well-water by the time the measurements were made, leading to the conclusion that the suspected tubular defect might well be rapidly reversible (Moss et al., 1983; Moss, 1985).

In a pilot study conducted in 1993 in three communities in Saskatchewan, Canada, there was a statistically significant association ( $p = 0.03$ ) between increasing but normal levels of urine albumin (measured as mg/mmol creatinine) and the uranium cumulative index. The cumulative index was calculated for each study participant as the product of the uranium concentration in drinking-water, the number of cups of water consumed per day, and the number of years lived at the current residence (Mao et al., 1995). The study was conducted with 100 participants

in three different areas with mean uranium levels ranging from 0.71 (control) to 19.6  $\mu\text{g/litre}$ . Urine albumin levels ranged from 0.165 to 16.1 mg/mmol creatinine, with eight participants having "elevated" urine albumin concentrations ( $>3.0$  mg/mmol creatinine). Three participants had serum creatinine concentrations of  $>120$   $\mu\text{mol/litre}$  (range 50–170  $\mu\text{mol/litre}$ ), which is reportedly indicative of prevalent renal damage. It should be noted, however, that diabetics were not excluded from the study, although diabetic status and age, known risk factors for renal dysfunction, were factored into the statistical analysis of the results. According to the authors, microalbuminuria has been shown to be a sensitive indicator of early renal disease.

### 7. PROVISIONAL GUIDELINE VALUE

There are insufficient data regarding the carcinogenicity of uranium in humans and experimental animals. The guideline value for the chemical toxicity of uranium was therefore derived using a TDI approach. As no adequate chronic study was identified, the TDI was derived using the results of the most extensive subchronic study conducted to date in which uranium was administered in drinking-water to the most sensitive sex and species (Gilman et al., 1997a). In the 91-day study in rats, the LOAEL for degenerative lesions in the proximal convoluted tubule of the kidney in males was considered to be 0.96 mg of uranyl nitrate hexahydrate per litre, which is equivalent to 0.06 mg of uranium per kg of body weight per day.

A TDI of 0.6  $\mu\text{g/kg}$  of body weight per day was derived using the LOAEL of 60  $\mu\text{g/kg}$  of body weight per day and an uncertainty factor of 100 (for intra- and interspecies variation). There is no need to apply an additional uncertainty factor to account for the use of a LOAEL instead of a NOAEL because of the minimal degree of severity of the lesions being reported. Also, an additional uncertainty factor for the length of the study (91-day) is not required because the estimated half-life of uranium in the kidney is 15 days, and there is no indication that the severity of the renal lesions will be exacerbated following continued exposure.

This TDI yields a guideline value of 2  $\mu\text{g/litre}$  (rounded figure), assuming a 60-kg adult consuming 2 litres of drinking-water per day and a 10% allocation of the TDI to drinking-water. This value would be protective, based on associations for subclinical renal effects reported in preliminary epidemiological studies.

Several methods are available for the removal of uranium from drinking-water, although some of these methods have been tested at laboratory or pilot scale only. Coagulation using ferric sulfate or aluminium sulfate at optimal pH and coagulant dosages can achieve 80–95% removal of uranium, whereas at least 99% removal can be achieved using lime softening, anion exchange resin, or reverse osmosis processes. In areas with high natural uranium levels, a value of 2  $\mu\text{g/litre}$  may be difficult to achieve with the treatment technology available (WRC, 1997).

The guideline value for uranium is provisional because it may be difficult to achieve with the treatment technology available, because of limitations in the key study, namely the lack of a dose-response relationship (no NOEL) despite the wide range of administered doses, and because of insufficient information on the degree and severity of the pathological examinations. It should be noted that there are several human studies under way that may provide helpful additional data.

## 8. REFERENCES

- Anthony ML et al. (1994) Studies of the biochemical toxicology of uranyl nitrate in the rat. *Archives of toxicology*, 68:43-53.
- Berlin M, Rudell B (1986) Uranium. In: Friberg L, Nordberg GF, Vouk VB, eds. *Handbook on the toxicology of metals*, 2nd ed. Amsterdam, Elsevier Science Publishers, pp. 623-637.
- Boomer DW, Powell MJ (1987) Determination of uranium in environmental samples using inductively coupled plasma mass spectrometry. *Analytical chemistry*, 59:2810-2813.
- Campbell DCC (1985) *The development of an animal model with which to study the nephrotoxic effects of uranium-contaminated drinking water*. Halifax, Nova Scotia, Dalhousie University (M.Sc. thesis).
- Cheng YL, Lin JY, Hao XH (1993) Trace uranium determination in beverages and mineral water using fission track techniques. *Nuclear tracks and radiation measurements*, 22(1-4):853-855.
- Cothern CR, Lappenbusch WL (1983) Occurrence of uranium in drinking water in the US. *Health physics*, 45:89-99.
- Domingo JL (1993) Chemical toxicity of uranium. *Toxicology and ecotoxicology news*, 2(3):74-78.
- Domingo JL et al. (1987) Acute toxicity of uranium in rats and mice. *Bulletin of environmental contamination and toxicology*, 39:168-174.
- Domingo JL et al. (1989a) The developmental toxicity of uranium in mice. *Toxicology*, 55(1-2):143-152.
- Domingo JL et al. (1989b) Evaluation of the perinatal and postnatal effects of uranium in mice upon oral administration. *Archives of environmental health*, 44(6):395-398.
- Durbin PW, Wenn ME (1976) Metabolism and effects of uranium in animals. In: *Conference on occupational health experience with uranium*. Washington, DC, US Energy Research and Development Administration, pp. 68-129 (available from US National Technical Information Service).
- Fisenne IM, Pery PM (1985) Isotopic U concentration in human blood from New York City donors. *Health physics*, 49:1272-1275.
- Fisenne IM, Welford GA (1986) Natural U concentration in soft tissues and bone of New York City residents. *Health physics*, 50(6):739-746.
- Fisenne IM et al. (1987) The daily intake of  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{226}\text{Ra}$  by New York City residents. *Health physics*, 53:357-363.
- Gans I (1985) Natural radionuclides in mineral waters. *Science of the total environment*, 45:93-99.
- Gilman AP et al. (1997a) Uranyl nitrate: 28-day and 91-day toxicity studies in the Sprague-Dawley rat. *Fundamental and applied toxicology* (in press).
- Gilman AP et al. (1997b) Uranyl nitrate: 91-day toxicity studies in the New Zealand white rabbit. *Fundamental and applied toxicology* (in press).
- Gilman AP et al. (1997c) Uranyl nitrate: 91-day exposure and recovery studies in the New Zealand white rabbit. *Fundamental and applied toxicology* (in press).
- Greenwood NN, Earnshaw A (1984) *Chemistry of the elements*. Oxford, Pergamon Press.
- Harley JH (1988) Naturally occurring sources of radioactive contamination. In: Harley JH, Schmidt GD, Silini G, eds. *Radionuclides in the food chain*. Berlin, Springer-Verlag.
- Hirose K, Sugimura Y (1981) Concentration of uranium and the activity ratio of  $^{234}\text{U}/^{238}\text{U}$  in surface air: effect of atmospheric burn-up of Cosmos-954. *Meteorology and geophysics*, 32:317 [cited in Fisenne & Welford, 1986].
- Hu Q, Zhu S (1990) Induction of chromosomal aberrations in male mouse germ cells by uranyl fluoride containing enriched uranium. *Mutation research*, 244:209-214.
- Hursh JB, Spoor NJ (1973) Data on man. In: Hodge HC et al., eds. *Handbook of experimental pharmacology*, Vol. 36. Uranium, plutonium, transplutonic elements. Berlin, Springer-Verlag, pp. 197-240.
- Igarashi Y, Yamakawa A, Ikeda N (1987) Plutonium and uranium in Japanese human tissues. *Radioisotopes*, 36:433-439.
- Kahlos H, Asikainen M (1980) Internal radiation doses from radioactivity of drinking water in Finland. *Health physics*, 19:108-111.
- Kreiger HL, Whittaker EL (1980) *Prescribed procedures for measurement of radioactivity in drinking water*. Washington, DC, US Environmental Protection Agency (EPA-600/4-80-032) [cited in Blanchard RL et al. (1985) Radiological sampling and analytical methods for national primary drinking water regulations. *Health physics*, 48(5):587-600].
- Landa ER, Councell TB (1992) Leaching of uranium from glass and ceramic foodware and decorative items. *Health physics*, 63:343-348.
- La Touche YD, Willis DL, Dawydiak OI (1987) Absorption and biokinetics of U in rats following an oral administration of uranyl nitrate solution. *Health physics*, 53(2):147-162.
- Leggett RW (1989) The behaviour and chemical toxicity of U in the kidney: a reassessment. *Health physics*, 57(3):365-383.
- Lide DR, ed. (1992-93) *Handbook of chemistry and physics*. Boca Raton, FL, CRC Press.
- Lin RH et al. (1993) Cytogenetic toxicity of uranyl nitrate in Chinese hamster ovary cells. *Mutation research*, 319:197-203.
- Llobet JM et al. (1991) Influence of chronic exposure to uranium on male reproduction in mice. *Fundamental and applied toxicology*, 16:821-829.
- Lucas HF, Markun F (1970) Thorium and uranium in blood, urine and cigarettes. In: *Argonne National Laboratory Radiation Physics Division Annual Report, Part 2*. Argonne, IL, Argonne National Laboratory, pp. 47-52 (ANL-7760).
- Malenchenko AF, Barkun NA, Guseva GF (1978) Effect of uranium on the induction and course of experimental autoimmune ophthalmitis and thyroiditis. *Journal of hygiene, epidemiology, microbiology and immunology*, 22(3):268-277.
- Mao Y et al. (1995) Inorganic components of drinking water and microalbuminuria. *Environmental research*, 71:135-140.
- Maynard EA, Hodge HC (1949) Studies of the toxicity of various uranium compounds when fed to experimental animals. In: Voeglin C, ed. *Pharmacology and toxicology of uranium compounds*. New York, NY, McGraw-Hill, pp. 309-376.
- Maynard EA, Downs WL, Hodge HC (1953) Oral toxicity of uranium compounds. In: Voeglin C, Hodge HC, eds. *Pharmacology and toxicology of uranium compounds. Chronic inhalation and other studies*. New York, NY, McGraw-Hill, pp. 1121-1369.
- McDonald-Taylor CK, Singh A, Gillman A (1997) Uranyl nitrate-induced proximal tubule alterations in rabbits: a quantitative analysis. *Journal of toxicologic pathology*, 25(4):381-389.
- McDonald-Taylor CK et al. (1992) Uranyl nitrate-induced glomerular basement membrane alterations in rabbits: a quantitative analysis. *Bulletin of environmental contamination and toxicology*, 48:367-373.
- Moss MA (1983) *Chronic low level uranium exposure via drinking water - clinical investigations in Nova Scotia*. Halifax, Nova Scotia, Dalhousie University (M.Sc. thesis).
- Moss MA et al. (1983) Uranium in drinking water - report on clinical studies in Nova Scotia. In: Brown SS, Savory J, eds. *Chemical toxicology and clinical chemistry of metals*. London, Academic Press, pp. 149-152.
- Nozaki T et al. (1970) Neutron activation analysis of uranium in human bone, drinking water and daily diet. *Journal of radioanalytical chemistry*, 6:33-40.
- OMEE (1996). *Monitoring data for uranium - 1990-1995*. Toronto, Ontario, Ontario Ministry of Environment and Energy, Ontario Drinking Water Surveillance Program.
- Ortega A et al. (1989) Evaluation of the oral toxicity of uranium in a 4-week drinking-water study in rats. *Bulletin of environmental contamination and toxicology*, 42:935-941.
- Patermain JL et al. (1989) The effects of uranium on reproduction, gestation, and postnatal survival in mice. *Ecotoxicology and environmental safety*, 17:291-296.
- Roessler CF et al. (1979) Uranium and radium-226 in Florida phosphate materials. *Health physics*, 37:267-269.
- Singh NP, Wenn ME (1988) Determinations of actinides in biological and environmental samples. *Science of the total environment*, 70:187-203.
- Singh NP et al. (1990) Daily U intake in Utah residents from food and drinking water. *Health physics*, 59(3):333-337.

- Sontag W (1986) Multicompartment kinetic models for the metabolism of americium, plutonium and uranium in rats. *Human toxicology*, 5:163-173.
- Sullivan MF et al. (1986) Influence of oxidizing or reducing agents on gastrointestinal absorption of U, Pu, Am, Cm and Pm by rats. *Health physics*, 50(2):223-232.
- Tracy BL et al. (1992) Absorption and retention of uranium from drinking water by rats and rabbits. *Health physics*, 62(1):65-73.
- US EPA (1990) *Occurrence and exposure assessment for uranium in public drinking water supplies*. Report prepared by Wade Miller Associates, Inc. for the Office of Drinking Water, US Environmental Protection Agency, 26 April 1990 (EPA Contract No. 68-03-3514).
- US EPA (1991) *Review of RSC analysis*. Report prepared by Wade Miller Associates, Inc. for the US Environmental Protection Agency, 9 May 1991 [follow-up to US EPA, 1990].
- WRC (1997) *Treatment technology for aluminium, boron and uranium*. Document prepared for WHO by the Water Research Centre, Medmenham, and reviewed by S. Clark, US EPA; A. van Dijk-Looijaard, KIWA, Netherlands; and D. Green, Health Canada.
- Wrenn ME et al. (1985) Metabolism of ingested U and Ra. *Health physics*, 48:601-633.
- Yuile CL (1973) Animal experiments. In: Hodge HC et al., eds. *Handbook of experimental pharmacology*. Vol 36. Uranium, plutonium, transplutonic elements. Berlin, Springer-Verlag, pp. 165-195.

## CYANOBACTERIAL TOXINS: MICROCYSTIN-LR

First draft prepared by  
S. Gupta

Bureau of Chemical Hazards, Environmental Health Directorate  
Health Protection Branch, Health Canada, Ottawa, Ontario, Canada

No guideline values were proposed for cyanobacterial toxins in the second edition of the WHO *Guidelines for drinking-water quality*. As microcystins (produced by cyanobacteria, or blue-green algae) are extremely toxic and are often associated with poisonings in humans and animals, the Coordinating Committee for the Updating of WHO *Guidelines for drinking-water quality* decided that guideline values for cyanobacterial toxins were needed.

## 1. GENERAL DESCRIPTION

## 1.1 Identity

The cyanobacteria, also known as blue-green algae, owe their name to the presence of photosynthetic pigments. Cyanobacteria are a major group of bacteria that occur throughout the world. Freshwater cyanobacteria may accumulate in surface water supplies as "blooms" and may concentrate on the surface as blue-green "scums."

Some species of cyanobacteria produce toxins, which are classified according to their mode of action into hepatotoxins (e.g. microcystins), neurotoxins (e.g. anatoxins), skin irritants, and other toxins. Both hepatotoxins and neurotoxins are produced by cyanobacteria commonly found in surface water and therefore are of relevance to water supplies (Carmichael, 1992; Fawell et al., 1993).

The hepatotoxins are produced by various species within the genera *Microcystis*, *Anabaena*, *Oscillatoria*, *Nodularia*, *Nostoc*, *Cylindrospermopsis*, and *Umezakia*, although not all strains do so (Fawell et al., 1993; AWWA, 1995). Most hepatotoxins (all cyclic heptapeptides) are microcystins. At least 50 congeners of microcystins are known (Carmichael, 1994), and several of these may be produced during a bloom. The chemical structure of microcystins includes two variable amino acids and an unusual aromatic amino acid, ADDA (3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid), containing a substituted phenyldecadienoic acid (Botes et al., 1985). Different microcystins have different lipophilicities and polarities, which could affect their toxicity. Microcystin-LR was the first microcystin chemically identified; to date, most work has been conducted using this microcystin. It has been associated with most of the incidents of toxicity involving microcystins in most countries (Fawell et al., 1993). Microcystin-LR is a cyclic heptapeptide with a molecular weight of about 1000 daltons.

Neurotoxins are not considered as widespread in water supplies, and they do not appear to pose the same degree of risk from chronic exposure as microcystins (Fawell et al., 1993; AWWA, 1995). The neurotoxins, such as anatoxin-a and -a(s),

# EXHIBIT N

BEFORE THE WATER QUALITY CONTROL COMMISSION  
FOR THE STATE OF NEW MEXICO

IN THE MATTER OF THE PETITION  
TO AMEND GROUND WATER  
QUALITY STANDARDS CONTAINED IN  
20.6.2 NMAC



GROUND WATER QUALITY BUREAU,

Petitioner.

No. WQCC 02-18(A)

FINAL ORDER AND STATEMENT OF REASONS

THIS MATTER came before the New Mexico Water Quality Control Commission ("Commission") upon petition filed by the Ground Water Quality Bureau ("GWQB") of the New Mexico Environment Department ("NMED") proposing amendments to 20.6.2.7 and 20.6.2.3103 NMAC. A public hearing was held on September 22- 26, 2003, and March 9-10, 2004. A public meeting with deliberations in this matter was held on June 8, 2004. The Commission heard all the evidence, deliberated, and voted to adopt the petition in full, except that it did not add manganese to 20.6.2.7.VV and it changed the ground water human health standard for uranium in 20.6.2.3103.A NMAC to 30µg/L, for the reasons set forth below.

Findings of Fact

Procedural Findings

1. On or about October 24, 2002, NMED filed a Petition to Amend Groundwater Quality Standards Contained in 20.6.2 NMAC of the Commission Regulations, and Request For Hearing. The Petition included a copy of the proposed amendments to the standards. NMED Findings of Fact ("FOF") #1.

2. On or about October 30, 2002, the Commission issued its Notice of Docketing. NMED FOF #2.
3. On or about November 10, 2002, NMED and New Mexico Mining Association ("NMMA") filed a Joint Motion to Continue the Hearing beyond the ninety (90) day setting requirement.
4. On or about November 12, 2002, the Commission orally granted the November 10, 2002, motion and set the matter for hearing for April 8, 2003. NMED FOF #2. The Commission selected the Chairperson as the Hearing Officer.
5. On or about March 26, 2003, the Commission Chairperson issued an Order Rescheduling Hearing for June 10, 2003. NMED FOF #3.
6. On or about April 18, 2003, Notice was issued setting a procedural schedule and giving notice that hearings would be held on June 10, 2003. NMED FOF # 4.
7. On or about May 9, 2003, the NMMA filed a Motion to Postpone Hearing. NMED FOF # 5.
8. On or about May 22, 2003, Eastern Navajo Diné Against Uranium Mining-Concerned Citizens of T'iistsóóz Nideeshgizh ("ENDAUM-CCT") filed its Response to Motion to Postpone Hearing.
9. On or about May 23, 2003, the Commission Chairperson issued an Order Denying NMMA's Motion to Postpone Hearing. NMED FOF # 6.
10. On or about June 4, 2003, NMMA filed a letter requesting a postponement of the hearing. NMED FOF # 7.

11. On or about June 5, 2003, the Commission Chairperson issued an Order Granting the June 4, 2003, Letter Motion to Postpone the Hearing, stating that the hearing would be postponed until no later than September 2003. NMED FOF # 8.
12. On or about July 8, 2003, the Commission set the hearing to begin on September 22, 2003.
13. On or about August 1, 2003, NMED moved to enforce the Commission's June 5<sup>th</sup> Order, requesting that NMMA be required to produce and discuss its technical presentations. NMED FOF # 9.
14. On or about August 4, 2003, Notice of hearing was duly published in the Albuquerque Journal. NMED Ex. 4. NMED FOF # 10.
15. On or about August 8, 2003, NMMA filed its Response to NMED's Motion to Enforce. NMED FOF # 12.
16. On or about August 11, 2003, ENDAUM-CCT filed its Response to the NMED Motion to Enforce. NMED FOF # 13.
17. On or about August 15, 2003, Notice of hearing was duly published in the New Mexico Register. NMED Ex. 5. NMED FOF # 11.
18. On or about August 18, 2003, NMED filed a Reply to the NMMA Response. NMED FOF # 14.
19. On or about September 8, 2003, NMED moved to remove any hearing on its Motion to Enforce from the agenda of the Commission's September 9, 2003, meeting. NMED FOF # 15. Since this was a voluntary action, no Order was needed.
20. On or about September 18, 2003, the Chairman of the WQCC issued an Order Appointing a Hearing Officer. NMED FOF # 16.

21. The notice of hearing published in this proceeding gave notice that a public hearing would be held before the WQCC to consider proposed amendments to Sections 20.6.2.7 and 20.6.2.3103 NMAC, beginning on September 22, 2003 at 9:00 am, in room 317 of the State Capitol Building. It further stated: "The amendments are to the toxic pollutant criteria and water quality standards of the Water Quality Control Commission Regulations. The proposed amendments will add 2,6, DNT, HMX, RDX, TNT, manganese, MTBE and perchlorate to the Commission's toxic pollutant listing, and will change the existing groundwater standard for Uranium from 5 mg/L<sup>1</sup> to 0.007 mg/L.<sup>2</sup> The New Mexico Environment Department is the proponent of the proposed amendments." The notice also directed the reader to an NMED website where a redline version of the proposed amendments could be viewed. NMED Exhibit. 3.
22. A public hearing on the petition was held beginning at 9:00 on September 22, 2003 in Santa Fe, New Mexico, in accordance with the Commission's rule-making guidelines, the Commission's April 18, 2003 Notice, and the Commission's June 5, 2003 Order. At the hearing all persons were provided a reasonable opportunity to present evidence and conduct cross-examination. NMED FOF # 18.

### Substantive Findings

#### **Narrative Standards**

1. NMED proposed that the definition of "toxic pollutant" at 20.6.2.7.VV NMAC which lists potential toxic pollutants be amended to add 2,6 DNT, RDX, HMX and TNT (under

---

<sup>1</sup> 5000 µg/L

<sup>2</sup> 7µg/L

the heading "high explosives") and also MTBE, manganese and Perchlorate. In addition 2,4 DNT which is already on the listing would be moved under the heading "high explosives." NMED Ex. 1.<sup>3</sup> NMED FOF # 23.

2. The contaminants identified in 20.6.2.VV NMAC are considered to be "narrative standards." NMED Ex. 10, p. 3. NMED FOF # 24.
3. NMED subsequently withdrew its proposal to add manganese to the list of contaminants in 20.6.2.7.VV NMAC. Tr. 9-24-03, p: 598. NMED FOF # 25.
4. "Toxic pollutant" is defined in the regulations as "a water contaminant or combination of water contaminants in concentrations which, upon exposure, ingestion, or assimilation either directly from the environment or indirectly by ingestion through food chains, will unreasonably threaten to injure human health, or the health of animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit. As used in this definition injuries to health include death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, genetic mutation, physiological malfunctions or physical deformations in such organisms or their offspring." To be considered a toxic pollutant, the contaminant must be one or a combination of contaminants on the list of potential toxic pollutants. NMED Ex. 10, p. 3; 20.6.2.7.VV NMAC. The narrative standard does not set a level for the contaminant, but only identifies the contaminants for which a level may be set in a discharge permit.  
NMED FOF # 26.
5. Under the regulations, if a discharger is going to discharge water to the environment that contains one or more of the constituents listed as a "potential toxic pollutant" in the

---

<sup>3</sup> Method of Citation.

- (a) Hearing transcript. Transcript ("Tr.") Date, page #.
- (b) Exhibits. Party, Ex. #.

narrative standards, the department will conduct an evaluation and determine, based upon publicly available scientific information, whether a limit for the discharge should be established by permit. 20.6.2.1201 NMAC. NMED FOF # 27.

6. To be included on the list of potential toxic pollutants, "credible scientific data and other evidence appropriate under the Water Quality Act" must show that at some level, the constituent may be a toxic pollutant, as defined at 20.6.2.7.VV. NMSA 1978, §74-6-4C (2001). NMED FOF # 28.
7. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that showed that the isomer 2,6 Dinitrotoluene is a neurotoxin and a hematological toxin and has the potential to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, genetic mutation, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit, and is also considered a carcinogen. NMED Ex. 12, 21. Tr. 9-22-03, pp. 46-57. NMED FOF # 29.
8. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that showed that the chemical Octahydro-1,3,5,7-Tetranitor-1,3,5,7-Tetrazocine (HMX) has a potential to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit. NMED Ex. 13. Tr. 9-22-03, pp. 46-57. NMED FOF # 30.
9. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that showed that the chemical Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) has a potential

to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit, and is a possible human carcinogen. NMED Ex. 14. Tr. 9-22-03, pp. 46-57. NMED FOF # 31.

10. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that the chemical 2,4,6 Trinitrotoluene (TNT) has a potential to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit, and is a possible human carcinogen. NMED Ex. 15. Tr. 9-22-03, pp. 46-57. NMED FOF # 32.

11. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that the chemical Methyl-Tertiary Butyl Ether (MTBE) has a potential to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred, cultivated or protected for use by man for food or economic benefit, and is a possible human carcinogen. NMED Ex. 17. Tr. 9-22-03, pp. 46-57. NMED FOF # 33.

12. NMED Witness, Mr. McQuillan, provided oral testimony and written exhibits that Perchlorate ( $\text{ClO}_4$ ) has a potential to cause death, histopathologic change, clinical symptoms of disease, behavioral abnormalities, physiological malfunctions or physical deformations in humans or in animals or plants which are commonly hatched, bred,

cultivated or protected for use by man for food or economic benefit. NMED Ex. 18. Tr. 9-22-03, pp. 46-57. NMED FOF # 34.

13. Mr. Nylander testified that the University of California supported the proposed narrative standards for high explosives (2,6 DNT, HMX and TNT) and perchlorate. Tr. 9-25-03, p. 994-996. NMED FOF # 93.

### Numeric Standards

14. The current human health standard for Uranium in groundwater at 20.6.2.3103A NMAC is 5000 µg/L. NMED has petitioned to amend it to 7µg/L. NMED FOF # 34.

15. The contaminants and levels identified at 20.6.2.3103A NMAC are “numeric standards.” NMED Ex. 10, p.3. NMED FOF # 36.

16. NMED presented the testimony of Mr. Dennis McQuillan, Dr. Johnnye Lewis, PhD., DABT<sup>4</sup>, and Dr. Don Molony, MD, in support of amending the Uranium standard to 7µg/L. NMED FOF # 39.

17. Groundwater standards protect the resource that public and private water systems may use for drinking water. Tr. 9-22-03, p. 44. NMED FOF # 43.

18. The proposed ground water standards are consistent with federal water quality requirements. McQuillan Testimony, NMED Ex. 10, p. 13-14. NMED FOF # 48.

19. Public water supply systems that are supplied by groundwater must comply with the federal Safe Drinking Water Act and EPA Minimum Contaminant Levels (MCL's) as part of producing drinking water for the public. McQuillan Testimony, NMED Ex. 10, p. 13-14. NMED FOF # 48.

---

<sup>4</sup> Diplomate of American Board of Toxicology.

20. The proposed standards are set at a level that would not allow permitted discharges to cause MCL violations in public water systems. McQuillan Testimony, NMED Ex. 10, p. 13-14. NMED FOF # 48.
21. Mr. McQuillan testified: “[A]pproximately ninety percent of the people in New Mexico drink groundwater. They rely solely on the groundwater as their source of drinking water. This includes public and private supply systems.” Tr. 9-22-03, p.58.
22. Mr. McQuillan testified: “Approximately ten percent of the population in New Mexico uses private domestic wells for water supply. These are not subject to protection of the Safe Drinking Water Act.” Tr. 9-22-03, p.58.
23. Mr. McQuillan testified: “And indeed, the state’s economy, many of the businesses rely on a source of clean groundwater.” Tr. 9-22-03, p.60.
24. The EPA has adopted a drinking water standard of 30 µg/L. ENDAUM-CCT FOF #98.
25. The EPA determined, based on available scientific evidence, that an exposure level of 20 µg/L would be protective of public health. EPA National Primary Drinking Water Regulations, Final Rule, 65 F.R. at 76713. The 20 µg/L level was rounded up from the calculated health-based level of 17 µg/L. Tr. 9-22-03, p. 225. However, the EPA determined that its drinking water standard should be 30 µg/L, because the incremental health benefits of requiring a 20 µg/L limit instead of a 30 µg/L limit are small in comparison to the costs saved by allowing a 30 µg/L limit instead of a 20 µg/L limit. 65 F.R. at 76714. NMED FOF # 75. Tr. 9-24-03, p. 854.
26. The United States Court of Appeals for the District of Columbia ruled that the EPA’s use of epidemiological data and non-human animal studies to set a drinking water standard

for uranium of 30 µg/L was reasonable. City of Waukesha, et. al. v. Environmental Protection Agency, 320 P.3d 228 (D.C. Cir. 2003). ENDAUM-CCT FOF #96.

27. Ms. Regina Romero, on behalf of New Mexico Municipal League and New Mexico Municipal Environmental Quality Association, testified: "We are expressing a concern about a public policy issue with respect to establishing a groundwater standard that is more stringent than the drinking water standard. Such a policy could create a paradox wherein water suitable for drinking would potentially require a groundwater discharge permit in order to discharge that very same water." Tr. 3-10-04, p.1862.

28. Ms. Romero was asked: "[A]re you saying that you thought the federal drinking water standard was appropriate?" She testified: "Yes, sir. We really do. There was such a terrific amount of research done and dialogue during those hearings with the Safe Drinking Water Act standards and regulations, and we felt that that had been pretty much addressed regarding uranium." Tr. 3-10-04, p. 1864.

29. Ms. Romero was asked: "[S]o you're saying it would be more consistent if we had our groundwater standard in line with the federal [drinking water] standard?" She testified: "Yes, sir." Tr. 3-10-04, p. 1864.

30. Mr. Samuel Montoya, on behalf of the Associations of Counties, testified: "We have some concern about the intended change ... to actually make the groundwater standard more stringent than the drinking water standard." Tr. 3-10-04, p. 1871.

31. Mr. Montoya was asked: "[W]ould you have a problem if the Commission adopted the federal standard as the federal health-based standard for municipal systems as the groundwater standard?" He testified: "No, I think that would be very good public policy." Tr. 3-10-04, p. 1873.

32. Health Canada has established a level of 20 µg/L for drinking water. Tr. 9-22-03, p. 221. NMED FOF # 75. Tr. 9-24-03, p. 854. ENDAUM-CCT FOF #97.
33. The Health Canada and EPA standards are both based on the Gilman rat study. Tr. 9-22-03, p. 221. ENDAUM-CCT FOF #99.
34. The World Health Organization recommends a level of 2 µg/L for drinking water. Tr. 9-22-03, p. 221. NMED FOF # 76. ENDAUM-CCT FOF #100.
35. Mr. McQuillan testified that NMED is proposing a uranium groundwater standard that is lower than the EPA drinking water standard because New Mexico has Native American and Hispanic populations that are more sensitive to the kidney toxicity posed by uranium relative to the United States at large. Tr. 9-22-03, p. 42. NMED FOF # 49.
36. NMED's witness, Dr. Lewis, is a board certified toxicologist, certified by the American Board of Toxicology. Tr. 9-22-03, p. 125. NMED FOF # 51.
37. Dr. Lewis and others prepared a report regarding the toxicological effects of Uranium on humans when ingested through water or other means. "Recommendations for a Uranium Health-Based Ground Water Standard" prepared by Barbara Malczewska-Toth, Ph.D., DABT, Orrin Myers, Ph.D., Chris Shuey, MPH Candidate, Johnnye Lewis, Ph.D., DABT ("Lewis Study"). Lewis Study, NMED Ex. 19. NMED FOF # 52.
38. Uranium is a naturally occurring, radioactive, heavy metal. Lewis Study, NMED Ex. 19, p. 2. NMED FOF # 53.
39. The most common form of uranium in groundwater is hexavalent, or plus-6. Tr. 9-22-03, p. 56-57. NMED FOF # 54.

40. The hexavalent form of uranium generally occurs as a uranyl ion (NMED Ex. 19, p. 2) which is rapidly absorbed through the small intestine. Lewis Study, NMED Ex. 19, p. 18. NMED FOF # 55.
41. Uranium's toxic effects are related to both its chemical and its radiological properties. Lewis Study, NMED Ex. 19, p. 25. NMED FOF # 56.
42. Uranium exhibits chemical toxicity at lower levels of concentration than it exhibits radiological toxicity, therefore considerations of chemical toxicity are of greater concern and should form the basis for developing the groundwater standard. Lewis Study, NMED Ex. 19, p. 25. NMED FOF # 57.
43. The kidney is the primary target organ for chemical toxicity of uranium. Lewis Study, NMED Ex. 19, p. 25, 27. Uranium exhibits chemical toxicity to the kidney. Tr. 9-22-04, p. 178-208. NMED FOF # 58.
44. Uranium toxicity adversely affects the function of the human kidney. Tr. 9-22-04, Pp. 196. NMED FOF # 59.
45. The Lewis Study used an exposure dose approach to estimating a numeric standard for uranium in drinking water that is protective of human health. Lewis Study, NMED Ex. 19, p. 53; NMED Ex. 21. This is an EPA recognized methodology for conducting health risk assessments and for developing ground water and/or drinking water numerical standards. Tr. 9-22-03, p. 229-230. The methodology of the Lewis study is consistent with scientific principles of toxicologic studies. Tr. 9-22-03, p. 230. NMED FOF # 60.
46. Dr. Donald Molony, MD testified on behalf of NMED. Tr. 9-22-03, p. 235. Dr. Molony is an attending physician and a professor of internal medicine in the Division of Renal Diseases and Hypertension in the Department of Internal Medicine at the University of

Texas Houston Medical School, an adjunct professor at the University of Texas MD Anderson Cancer Center and in the Department of Physiology and the graduate school and School of Public Health. He is also medical director of a large dialysis unit in Houston, caring for over a hundred patients in a renal care group. Id., p. 239. NMED FOF # 61.

47. Dr. Molony testified about the potential damage that may occur to the kidney as a result of exposures to uranium. Tr. 9-22-03, p. 244. Exposure to uranium causes proximal tubule injury. Id. p. 246. The risk to individuals exposed to a tubular toxicant such as uranium is increased if the person has existing glomerular damage, as occurs with diabetes mellitus. Id. P. 247. The risk from uranium for renal disease is substantially increased in individuals with diabetes, hypertension, preexisting kidney disease of any type, and other medical conditions. Tr. 9-23-03, p. 343-344. NMED FOF # 62.
48. Kidney disease is divided into 5 stages, with stage 1 being some damage and stage 5 being kidney failure. Tr. 9-22-03, p. 255-256, NMED Ex. 26, (Molony slide #6). If a person with stage 1 or 2 kidney disease is exposed to a second injury agent, that exposure will predictively increase the risk of progressing from Stage 1 to 2 to 3, and potentially increase the risk of progression to kidney failure. Id. p. 256, 267-268. NMED FOF # 63.
49. Taking measures to delay the need for dialysis for renal patients in New Mexico could save approximately \$70,000 per patient per year. New Mexico currently has approximately 2,000 patients on dialysis, and the rate is increasing by 2.25% per year. Tr. 9-22-04 p. 259-262. The annual health cost savings that would occur by taking steps to delay by one year the need for dialysis, by assuring that additional kidney injury does not occur to people with kidney disease, will be at least \$1.4 million. NMED FOF # 64.

50. Dr. Molony testified the human body needs a minimum of almost 2 liters of water per day in a warm dry climate. Tr. 9-23-03, p. 294. NMED FOF # 65.
51. Dr. Molony testified that the recommendations of the Lewis Study are based on a fair and unbiased evaluation of the medical literature and that the interpretations of the unique risks of individuals residing in New Mexico are medically and scientifically sound. He also agreed with the recommendations of the report to lower the allowable uranium in groundwater to the level of 7 $\mu$ g/L. Tr. 9-23-03, p. 345. NMED FOF # 66.
52. The Lewis Study determined that, depending on the assumptions used for the amount of water a person drinks daily, the health protective standard should be in the range between 6.4  $\mu$ g/L and 7.3  $\mu$ g/L. In the Lewis Study, an assumption of 2 L/day ingestion of drinking water resulted in a recommended allowed level of 7.3  $\mu$ g/L. If an assumption of 2.4 Liters per day water consumption is used, the recommended allowed level is 6.4  $\mu$ g/L of uranium in groundwater. Lewis Study, NMED Ex. 19. The Lewis Study recommended that, based on a review of all relevant technical information and scientific data available on the toxicity of uranium and epidemiological and basic research, that a level of 7 $\mu$ g/L would be protective of public health. NMED Ex. 19, Introduction, p. iii, Recommendation, p. 55. NMED FOF # 67.
53. The Lewis Study recommendation was based in part on the observation that the Native American and Hispanic communities in New Mexico have a high incidence of diabetes and associated kidney damage, and are sensitive populations. These populations are also collocated with the areas of uranium deposit in the state. Lewis Study, NMED Ex. 19, p. 37, 54. NMED FOF # 68.

54. The Lewis Study reviewed human exposure data and non-human animal studies of the toxicity of uranium. The human data alone were insufficient to establish a dose because of the relatively small sample sizes, the fact that the effects were subclinical, and the fact that people with existing kidney damage were excluded from the analysis. The human data, however, are consistent in identifying changes in the kidney damage in multiple studies associated with low-dose chronic exposure in healthy populations. Tr. 9-22-03, p. 203. Data from rabbit studies were of limited usability because of the dose range used and the co-occurrence of infection, but suggested the potential for increased sensitivity in animals with other physiologic stressors affecting the kidneys. Tr. 9-22-03, p. 204.
55. Data from rat studies by Gilman et al. are consistent with the largest body of data showing kidney damage. Data from rat studies was consistent in effect with the human and other animals studies, and had the strongest methodology of the studies available. Therefore, the weight-of-evidence approach utilized the full breadth of studies available to determine the toxic effect likely to occur with exposure to uranium and the range of exposures likely to cause toxicity. This approach supported using the rat study, the best designed and controlled of those available, as the basis for determining an effect level from which to calculate a safe exposure limit. Id. The data from rat studies showed kidney toxicity at the lowest dose tested, so the data provided a Lowest Observed Adverse Effect Level ("LOAEL") but not a No Observed Adverse Effect Level ("NOAEL"). Id. NMED FOF # 69.
56. Native American and Hispanic populations may be more sensitive to toxic insults from kidney toxicants because of the high prevalence of kidney disease and risk factors for

kidney disease, including hypertension and diabetes, in those populations. Tr. 9-22-03, p. 205. NMED FOF # 70.

57. The prevalence of diabetes in the New Mexico population is 3.3 times to 5 times the average in the United States. Tr. 9-22-03, p. 205. NMED FOF # 71.

58. Native American risk may also be increased as a result of land use patterns and the consumption of local foods. Tr. 9-22-03, p. 206. NMED FOF # 72.

59. The EPA exposure dose methodology for developing a numeric standard for uranium in drinking water that is protective of human health uses uncertainty factors to correct for uncertainties arising from various extrapolations within species, between species and other factors. EPA National Primary Drinking Water Regulations, Final Rule, 65 F.R. 76708. NMED FOF # 73.

60. The Lewis Study documented all uncertainty factors used and Dr. Lewis explained the professional judgment used in assigning the uncertainty factors. Tr. 9-22-03, p. 209 – 220, NMED Ex. 19. NMED FOF # 74.

61. A change in assignment of a number to any factor may change the overall result.

62. Both Dr. Lewis and NMMA's Witness Dr. Douglas Chambers acknowledged that calculating uncertainties is a matter of professional judgment. Tr. 9-22-03, p. 217-218, Tr. 9-25-03, p. 1130. ENDAUM-CCT FOF #94.

63. The Lewis Study was peer reviewed by Dr. Paul Kovnat, M.D., a practicing nephrologist. Dr. Kovnat found that the data support the conclusion reached by Dr. Lewis. NMED Ex. 20. NMED FOF # 78.

64. As scientists have gained more knowledge about the toxic affects of uranium, regulatory agencies have consistently reduced allowed levels of uranium in drinking water. Lewis Study, NMED Ex. 19, Figure N-1, p. 50. NMED FOF # 79.
65. Helen Flowers, M.S., testified on behalf of the New Mexico Department of Health. Tr. 9-23-03, p. 423. Ms. Flowers is an epidemiologist with the Department of Health. She testified that the current groundwater standard for uranium is in need of revision because it is at a level that would be associated with adverse health effects, including kidney damage and a potentially increased cancer risk. Tr. 9-23-03, p. 425. The current standard of 5000 µg/L is two orders of magnitude greater than the level at which health effects have been found by the EPA. Id. p. 425. NMED FOF # 80.
66. Ms. Flowers testified that the reason that the EPA drinking water standard was higher than the proposed NMED standard is that the NMED standard is a result of addressing the significant prevalence of sensitive populations with existing kidney disease in New Mexico, such as diabetics. Tr. 9-23-03, p. 428. She testified that this is an appropriate consideration, since diabetes prevalence in Native Americans is substantially higher than the national average and many Native Americans reside in areas with increased environmental concentrations of uranium. Id. She supported the standard proposed by NMED. NMED FOF # 81.
67. Dr. Ron Voorhees, M.D., M.P.H, testified on behalf of the New Mexico Department of Health. Dr. Voorhees is the Deputy State Epidemiologist. He is Board certified in public health and general preventative medicine. Dr. Voorhees testified that in his professional opinion, the proposal by the NMED to amend the uranium standard to 7 µg/L is based on

credible scientific evidence and is protective of public health. Tr. 9-23-03, Pp. 431- 433.  
NMED FOF # 82.

68. Dr. Voorhees testified that the Department of Health is especially concerned because of a higher rate of diabetes in the New Mexico population, which is primarily a function of the composition of the population in New Mexico being largely Hispanic and Native American. According to data prepared by the Health Department's Diabetes Prevention and Control Program, the rate of diagnosed diabetes among adult Native Americans in 1998 to 2001 was 10.5%, compared with a rate among Hispanic adults of 7.3% and among non-Hispanic white adults of 4.8%. Tr. 9-23-03, p. 434-435. NMED FOF # 83.

69. Dr. Voorhees also testified that he reviewed the studies regarding amendments to the narrative standards and found them to be based on credible scientific evidence and to be protective of public health. Tr. 9-23-03, p. 437. NMED FOF # 84.

70. Dr. John Fogarty, M.D., testified on behalf of ENDAUM. Tr. 9-24-03, p. 774. Dr. Fogarty is a family practice physician in Crownpoint, an assistant professor at the Department of Family Medicine at UNM and an adjunct faculty member at the Masters of Public Health Program at UNM. He also was director of the diabetes program at the Santa Fe Indian Hospital. Id., p. 775-777. NMED FOF # 85.

71. Dr. Fogarty testified that he concurred that the current standard for uranium in groundwater should be lowered dramatically and that the proposed standard of 7 $\mu$ g/L is reasonable given the sensitive population in New Mexico. Tr. 9-24-03, p. 778. NMED FOF # 86:

72. The presence of subclinical disease of the kidney, as shown by the presence of biomarkers is significant. Tr. 9-24-03, p. 787-788. Even subclinical disease requires

treatment. *Id.*, p. 790. Persons who develop subclinical disease have a much higher risk of developing diabetes progressing to renal failure. Tr. 9-24-03, p. 792. NMED FOF # 87.

73. Dr. Fogarty also made the point that many uranium miners have died due to exposure to uranium. He testified that had scientific uncertainties been resolved in a manner that was more protective of public health, the deaths could have been prevented. He concluded that a groundwater standard of  $7\mu\text{g/L}$  would protect current and future water supplies, acknowledges differences existing in New Mexico, and appropriately strengthens the EPA standard of  $30\mu\text{g/L}$  and the NRC standard of  $440\mu\text{g/L}$ . Tr. 9-24-03, p. 808-812. NMED FOF # 88.

74. Mr. Chris Shuey, M.P.H., testified on behalf of ENDAUM. Mr. Shuey directs the Uranium Impact Assessment Program on behalf of the Southwest Research and Information Center. Mr. Shuey holds a Masters of Public Health degree with a focus on environmental epidemiology. Tr. 9-24-03, p. 813. Mr. Shuey assisted in preparation of the Lewis Study. Mr. Shuey testified that the proposed standard of  $7\mu\text{g/L}$  is thoroughly defensible based on the rigorous analysis that has gone into the number, and that it satisfies epidemiological criteria for causality. *Id.*, p. 818. NMED FOF # 89.

75. Mr. Shuey testified about the types of scientific studies that epidemiologists rely upon. Tr. 9-24-03, p. 820-832. He testified that clinical studies of the effects of uranium on humans could not be done due to ethical issues, and that cross-sectional and case control studies were the limit of studies that could be done, because it would be wrong to knowingly subject people to a harmful exposure. Tr. 9-24-03, p. 832. Mr. Shuey testified about a study by Health Canada showing that people exposed to average

concentration ranges between 0.5µg/L and 19.6µg/L showed subclinical effects to their kidneys. Id., p. 840. NMED FOF # 90.

76. Mr. Shuey reviewed several of the studies of the health effects of uranium in water, and concluded that on whole, the weight of evidence is that the population studies and the cross-sectional studies show adverse effects of chronic ingestion of low levels of uranium at or below the level of the EPA drinking water standard. Tr. 9-24-03, p. 851. He stated that the proposed groundwater standard of 7µg/L is not based on a "single rat study." The Lewis Study was based on a comprehensive assessment of the available literature. Id. Mr. Shuey testified that the use by the Lewis study of the Gilman rat study to develop a proposed standard is standard practice used around the globe. Id. NMED FOF # 91.
77. Mr. Charles Nylander testified on behalf of the University of California Board of Regents. Tr. 9-25-03, p. 917. Mr. Nylander testified that he wanted the Commission to appreciate that the regulated community is concerned with a good contextual application of the regulations. NMED FOF # 92.
78. Mr. Nylander testified that it took no position on the proposed numeric standard for uranium. Tr. 9-25-03, p. 994-996. NMED FOF # 93.
79. Dr. Don Fisher, M.D., testified on behalf of the New Mexico Mining Association. Tr. 9-25-03, p. 1067. Dr. Fisher is board certified in toxicology and occupational medicine. Id., p. 1068. NMED FOF # 95.
80. Dr. Fisher testified that, based upon the studies cited in the Lewis Study, the strength of association between ingestion of uranium in drinking water and the development of overt disease is not clear. Tr. 9-25-03, p. 1077. He also testified that there are too many

variables to make any scientific statements in terms of drawing a line in the sand where uranium may have its initial effect on the kidney. Id., p. 1084. NMED FOF # 96.

81. Dr. Fisher stated that the current groundwater standard for uranium is too high for drinking water. Tr. 9-25-03, p. 1106. He did not make a recommendation as to what level it should be. Id. p. 1106-1115. He did testify that a limit of 30 µg/L would be protective of public health. Id., p. 1118. NMED FOF # 97.

82. Dr. Douglas B. Chambers, Ph.D. testified on behalf of the New Mexico Mining Association. Tr. 9-25-03, p. 1120. Dr. Chambers is an environmental consultant. Tr. 9-25-03, p. 1121. Dr. Chambers reviewed the Lewis Study through the perspective of a risk assessor (Id., p. 1129) and testified that in doing health risk assessments it is always necessary to make judgments and there are differences of opinion. Id., 1129-1130. NMED FOF # 98.

83. Dr. Chambers reviewed the various uncertainty factors and other assumptions used in the Lewis Study. In particular, he reviewed the Relative Source Contribution (Tr. 9-25-03, p. 1131-1135) assumptions about water intake (Id., p. 1136), adjusting for LOAEL to NOAEL (Id., p. 1149, 1154), adjusting for subchronic to chronic exposures (Id., p. 1152-1153), adjusting for interspecies variation (Id. p. 1152) and the factor for sensitive individuals (Id., p. 1158). However, Dr. Chambers did not testify that any single assumption or adjustment was unreasonable, and recognized that it was a judgment call. Tr. 9-25-03, p. 1204. NMED FOF # 99.

84. Uncertainties in the Lewis/Toth report result from the absence of probative human epidemiological studies. Tr. 9-23-03, p. 492. NMMA FOF #13.

85. Dr. Chambers testified that from a risk assessors perspective, he would recommend a drinking water standard of somewhere between 30 to 100  $\mu\text{g/L}$ . Tr. 9-25-03, p. 1188. He also testified that the current standard of 5000 $\mu\text{g/L}$  is not protective of public health. Id., p. 1216. NMED FOF # 100.
86. Dr. Chambers also testified that a standard for groundwater that could be expected to be used for domestic use should be the same as a drinking water standard. Tr. 9-25-03, p. 1209-1210. NMED FOF # 101.
87. Production of uranium in New Mexico is as low as it has been since 1953, and between New Mexico and Nebraska, employs only 85 people. There are no active mines or mills, and all but one of seven uranium mills in the state have been completely dismantled. McQuillan Testimony, NMED 10, p. 10. NMED FOF # 42.
88. Existing uranium operators are abating groundwater at mine and mill sites pursuant to approved discharge plans evaluated according to the existing standard of 5000 $\mu\text{g/L}$ . 9-26-03, p. 1267, 1270, 3-9-04, p. 1587-88. NMMA FOF #59.
89. At the time an existing mill operator meets all the conditions of its Nuclear Regulatory Commission ("NRC") license, it will transfer the site, including the area that represents the horizontal footprint of the tailings pile, to the Department of Energy in fee for perpetual stewardship. The Department of Energy will not allow a domestic water well or community water system to be constructed within these boundaries. 9-26-03, p. 1273, 3-10-04, p. 1825. NMMA FOF #62.
90. Mr. McQuillan testified that is feasible to treat the constituents under consideration to an acceptable concentration before a subsequent use. McQuillan Testimony, NMED Ex. 10, p. 12. Removal of contaminants can be accomplished by a number of methods,

depending on the constituent, including aeration, carbon filtration, distillation, ion exchange and reverse osmosis. McQuillan Testimony, NMED Ex. 10, p. 13. NMED FOF # 46.

### Conclusions of Law

1. **Authority.** The Commission has jurisdiction over this matter pursuant to the Water Quality Act ("Act"), NMSA 1978, Section 74-6-1 to 74-16-17 and 20.6.2 NMAC.
2. The Commission has jurisdiction to hear and decide this rule-making petition pursuant to NMSA 1978, Section 74-6-6.
3. NMED has authority to bring this rule-making petition. NMSA 1978, Section 74-6-6(B) (1993).
4. NMED has the burden of supporting its petition with substantial evidence in the record. NMSA 1978, Section 74-6-7 (B)(2) (1993).
5. The Commission may take action to accept, modify, or deny this rule-making petition.
6. The purpose of the Act is to abate and prevent water pollution. Bokum Res. Corp. v. N.M. Water Quality Control Comm'n, 93 N.M. 546, 555, 603 P.2d 285, 294 (1979).
7. This case is to consider the adoption of, or amendment to, narrative standards and numeric standards. NMSA 1978, Subsection 74-6-4C sets forth the duties of the Commission and matters to be considered in the adoption of standards. NMED COL #4.
8. A change to water quality standards must "at a minimum, protect the public health or welfare, enhance the quality of water and serve the purposes of the Water Quality Act." NMSA 1978, Section 74-6-4C. NMED FOF # 37.
9. The changes approved herein to New Mexico's water quality standards must respect the use and value of the water for water supplies, propagation of fish and wildlife, recreational purposes and agricultural, industrial and other purposes. NMSA 1978, Section 74-6-4C.

10. A change to water quality standards must be based upon “credible scientific data and other evidence appropriate under the Water Quality Act.” NMSA 1978, Section 74-6-4C. NMED FOF # 38.
11. The notice in this proceeding encompassed only a change to specific narrative standards in 20.6.2.7 NMAC and specific numeric standards in 20.6.2.3103 NMAC. It did not encompass changes to regulations that apply the standards. See The Regents of University of California v. New Mexico Water Quality Control Commission, COA No. 23,498 (2004).
12. The actions taken by the Commission to amend the petition in this proceeding must fall within the scope set forth in the public notice, or be a “logical outgrowth” of the proposed amendments. Small Refiner Lead Phase-Down Task Force v. United States Environmental Protection Agency, 705 F.2d 506 (D.C. Cir. 1983). BASF Wyandotte Corp., et al. v. Costle, 598 F. 2d 637, 642 (1<sup>st</sup> Cir. 1979). NMED COL #3.
13. NMSA 1978, Subsection 74-6-4C does not limit the Commission from considering other matters, such as the factors at subsection 74-6-4D, including the social and economic value of the sources of the contaminants, technical practicability and economic feasibility, and these factors will be admitted and weighed on a petition-by-petition basis.
14. However, consideration of the social and economic value of the sources of the contaminants, technical practicability and economic feasibility includes the fact that a responsible party has the opportunity, at the time of the application of the regulations to a particular site, to petition NMED for a Technical Infeasibility determination, or to petition the Commission for an Alternative Abatement Standard under 20.6.2.4103

NMAC, at which time these issues can be considered on a site specific basis. NMED COL #6.

15. **Narrative Standards.** There is credible scientific evidence of the dangers of certain levels of 2,4 DNT, 2,6 DNT, HMX, TNT, MTBE, and Perchlorate in the groundwater.
16. The proposed amendments to the narrative standards will limit ground-water contaminant concentrations to levels that will not injure or interfere with health or welfare.
17. This is protective of public health and welfare because it will better ensure that people will not get sick.
18. This is protective of the quality of water and will better ensure a higher quality of water for humans and animals, which is beneficial for water supplies, propagation of fish and wildlife, recreation, and agricultural purposes.
19. There is substantial evidence in the record that the proposed amendments to the narrative standards are in the public interest, even considering the social and economic value of the sources of water contaminants for industrial uses.
20. Compliance with the proposed narrative standards is technically practical and economically reasonable for both pollution prevention and abatement. On a site specific basis, responsible persons also have the opportunity to petition for Technical Infeasibility or Alternative Abatement Standards. NMED COL #10.
21. Amending the narrative standards does not affect the manner in which the standards are applied by the regulations or by NMED. NMED COL #15.
22. The narrative groundwater standards, as amended, will apply to future discharges onto or below the surface of the ground, and will apply to the abatement of contamination existing at the time of abatement. NMED COL #16.

23. Based on Substantive Findings of Fact #1-13, the Commission concludes that credible scientific data exists in this proceeding to support amending the narrative standards found within the definition of "toxic pollutant" at 20.6.2.7.VV NMAC to move 2,4 DNT, and to add 2,6 DNT, HMX and TNT, to the list of potential pollutants under the heading "high explosives" and support adding MTBE and Perchlorate to the list of potential toxic pollutants. NMED COL #7. NMED withdrew its proposal to add manganese to the list of contaminants in 20.6.2.7.VV NMAC and therefore this item will not be included in this action.
24. **Numeric Standards.** There is credible scientific evidence of the dangers of certain levels of uranium in the groundwater.
25. Witnesses for both sides acknowledged that the current numeric groundwater standard is not protective of public health and welfare.
26. Witnesses for both sides acknowledged that a drinking water standard at 30 µg/L was reasonable figure for a drinking water standard.
27. EPA has set the drinking water standard at 30 µg/L.
28. Amending the numeric uranium groundwater standard to 30 µg/L would not interfere with federal drinking water quality requirements or interfere with the work at public and private water systems.
29. The purpose of the groundwater standards "is to protect all ground water of the state of New Mexico which has an existing concentration of 10,000 mg/l or less TDS, for present and potential use as domestic and agricultural water supply..." 20.6.2.3101.A NMAC.
30. Based on the Act's overall intent, the Commission has interpreted this language to mean that if there is groundwater with less than 10,000 milligrams per liter of TDS, there is a

rebuttable presumption that the water is protectable for present and reasonably foreseeable future use.

31. A drinking water numeric standard is translatable to a groundwater standard because the Act's purpose is to protect New Mexicans who consume this protectable water.
32. A drinking water numeric standard is translatable to a groundwater standard because ten percent of New Mexicans use untreated groundwater directly as drinking water.
33. A drinking water numeric standard is translatable to a groundwater standard because ninety percent of New Mexicans use groundwater as its source of drinking water.
34. Setting the groundwater standard to the same number as the drinking water standard will provide uniformity and clarity to the municipalities, counties, businesses, and the public.
35. The proposed amendment to the numeric standards will limit ground-water contaminant concentrations to levels that will not injure or interfere with health or welfare.
36. This is protective of public health and welfare because it will better ensure that people will not get sick.
37. This is protective of the quality of water and will better ensure a higher quality of water for humans and animals, which is beneficial for water supplies, propagation of fish and wildlife, recreation, and agricultural purposes.
38. There is substantial evidence in the record that the proposed amendments to the narrative and numeric standards are in the public interest, even considering the social and economic value of the sources of water contaminants for industrial uses.
39. Amending the numeric uranium standard to 30 µg/L does not affect the manner in which the standards are applied by the regulations or by NMED. NMED COL #25.

40. If compliance with the amended numeric standard is not technically practical and economically reasonable for both pollution prevention and abatement, a party has a remedy by petitioning for Technical Infeasibility or Alternative Abatement Standards.

NMED COL #20.

41. Based on Substantive Findings of Fact #14-#90, the Commission concludes that credible scientific data supports amending the numeric standard for uranium from 5000 µg/L to 30 µg/L.

#### ORDER

Based upon these Findings of Fact and Conclusions of Law, a quorum of the Commission renders the following decision and order:

IT IS THEREFORE ORDERED that:

1. The definition of "toxic pollutant" at 20.6.2.7.VV NMAC that lists potential toxic pollutants shall be amended to add 2,6 DNT, RDX, HMX and TNT (under the heading "high explosives") and also MTBE, and Perchlorate. In addition 2,4 DNT which is already on the listing shall be moved under the heading "high explosives."
2. The human health standard for uranium in groundwater at 20.6.2.3103A NMAC shall be amended from 5000µg/L to 30µg/L.
3. For purposes of application of the amended numeric uranium standard to past and current water discharges resulting in a violation of the new standard, the new standard will not become effective until June 1, 2007. For any new water discharges, the standard will become effective

September 1, 2004, or whenever it is properly filed with State Records Center and Archives, whichever date is later.

4. All other parts become effective September 1, 2004, or whenever it is properly filed with State Records Center and Archives, whichever date is later.
5. The proposal is adopted for any or all of the reasons stated in these paragraphs.



Derrith Watchman-Moore, Chairperson  
On behalf of the Commission

Dated: 8-18-04

AUG 20 2004

STATE OF NEW MEXICO  
WATER QUALITY CONTROL COMMISSION



IN THE MATTER OF THE PETITION  
TO AMEND GROUND WATER  
QUALITY STANDARDS CONTAINED IN  
20.6.2 NMAC

CERTIFICATE OF SERVICE

I hereby certify that the Final Order and Statement of Reasons in the above captioned case was hand delivered to Chuck Noble, 1190 St. Francis Drive, Santa Fe, NM 87501 and sent certified mail to the party listed below on August 18, 2004. A copy will be provided to the Water Quality Control Commission members and Commission Counsel at the next meeting, scheduled for September 14, 2004.

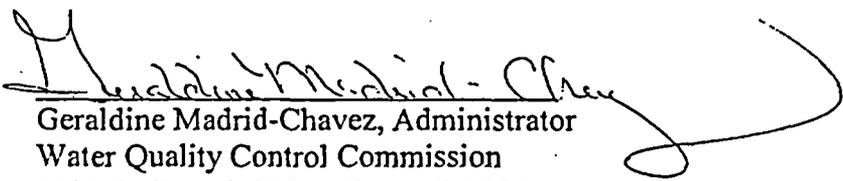
Eric D. Jantz  
New Mexico Environmental Law Center  
1405 Luisa Street  
Suite 5  
Santa Fe, NM 87505

Stephen J. Lauer  
Comeau, Maldegen, Templeman & Indall  
Attorneys At Law  
141 East Palace Avenue  
P.O. Box 669  
Santa Fe, NM 87504-0669

Louis Rose  
Montgomery & Andrews, PA  
325 Paseo de Peralta  
Post Office Box 2307  
Santa Fe, NM 87504-2307

Stuart R. Butzier, Esq.  
Modrall Sperling Roehl Harris & Sisk, PA  
PO Box 2168  
Albuquerque, NM 87103-2168

Lyle D. Riggs, Esq.  
Gallagher & Kennedy, PA  
2525 E. Camelback Road  
Phoenix, AZ 85016-9225

  
Geraldine Madrid-Chavez, Administrator  
Water Quality Control Commission  
1190 St. Francis Drive, Room S-2054  
Santa Fe, New Mexico 87502  
(505) 827-2425 Phone  
(505) 827-2836 Fax

---

**EXHIBIT O**

# **Recommendations for a Uranium Health-Based Ground Water Standard**

*Prepared for the*  
New Mexico Environment Department  
Ground Water Quality Bureau  
1190 St. Francis Drive, Santa Fe, New Mexico

*Prepared by*  
Barbara Malczewska-Toth, Ph.D., DABT\*  
Orrin Myers, Ph.D.\*, Chris Shuey, MPH Candidate\*\*  
Johnnye Lewis, Ph.D., DABT\*  
\*UNM Community Environmental Health Program  
University of New Mexico Health Sciences Center  
\*\*Southwest Research and Information Center

Final May 2003

## EXECUTIVE SUMMARY

A uranium health-based standard of 0.007 mg/L is recommended to protect all ground water of the state of New Mexico that has an existing concentration of 10,000 mg/L or less total dissolved solids (TDS) for present and potential future use as a domestic and agricultural water supply. This recommended standard is based solely on health protection, and is therefore lower than the current New Mexico Water Quality Control Commission regulation of 5 mg/L and the new Environmental Protection Agency's National Primary Drinking Water Standard of 0.03 mg/L. It is, however, greater than the state of California proposed Public Health Goal of 0.0002 mg/L (1999) and the World Health Organization guideline of 0.002 mg/L (1997).

This recommended standard is based on recent studies showing histological changes in the renal tubules of male Sprague-Dawley rats and New Zealand rabbits. Consistent with these non-human animal studies are studies showing changes in indicators of damage to the proximal tubules of the kidney (such as beta-2-microglobulin and gamma-glutamyl transferase levels in the urine) in human populations. This recommended standard has been calculated from a subchronic lowest-observed-adverse-effect level (LOAEL) of 0.06 mg/kg-day observed for kidney toxicity in rats. The LOAEL was adjusted by an uncertainty factor of 200 for extrapolation from rats to humans, from subchronic to lifetime exposure, from LOAEL to a no-observed-adverse-effect level (NOAEL), and for protection of sensitive subpopulations.

Uranium is a naturally occurring radioactive heavy metal, which is ubiquitously distributed throughout the earth's crust. Uranium is found in ground water and surface water due to its natural occurrence. Natural uranium contains more than 99%  $^{238}\text{U}$ , less than 1%  $^{235}\text{U}$ , and about 0.005%  $^{234}\text{U}$  by weight.  $^{234}\text{U}$  emits much more radioactivity per unit weight than  $^{238}\text{U}$  but it is much less prevalent than  $^{238}\text{U}$ . Radioactivity of natural uranium is of lesser health concern, however, than its chemical toxicity. The average natural uranium concentration in US surface water, ground water, and domestic water is 0.0016, 0.0047, and 0.0025 mg/L, respectively. In New Mexico domestic water supplies, the average uranium concentration is from about 0.00001 to 0.005 mg/L; however, concentrations as high as 0.92 mg/L occur in domestic wells in areas rich in uranium deposits. Because New Mexico has substantial uranium deposits, the uranium intake from water could represent as much as 70% of the total intake of uranium from all dietary components.

Although natural uranium is an emitter of ionizing radiation, which is carcinogenic, mutagenic, and teratogenic, there is no compelling evidence that uranium causes cancer following ingestion exposures. The primary toxic effect of uranium is on the kidneys. This effect has been observed in all species studied, including rats, rabbits, dogs, humans, and other primates. Primates also show greater absorption efficiency than other species, suggesting toxicity can occur at lower exposure levels. Based on this review, a health-based standard of 0.007 mg/L is recommended for natural uranium to protect all ground water of the state of New Mexico that has an existing concentration of 10,000 mg/L or less TDS for present and potential future use as a domestic and agricultural water supply. This recommended ground water standard is protective against both kidney toxicity and potential carcinogenic effects of ionizing radiation produced by natural uranium.

***V. Derivation of Health-Based Recommendations for Ground Water Standards***

As discussed in previous sections of this document, chemical toxicity of natural uranium to the kidney is the primary toxicity following ingestion exposures. This effect occurs at exposures lower than those associated with radiological toxicity, and at lower exposures than any of the other toxic effects related to chemical toxicity. Therefore, nephrotoxicity will be the basis for the derivation of the recommended standard.

#### ***V.A. Primary Ground Water Uses in New Mexico.***

In setting a ground water standard that is health-protective, the uses of that ground water that will lead to human exposure pathways must be considered. In New Mexico, the primary uses of ground water likely to result in human exposures are the following:

- Drinking and cooking
- Showering and bathing
- Produce irrigation
- Livestock watering.

Showering and bathing will result in primarily dermal and inhalation exposure routes. For uranium, the intake via these routes will be negligible relative to the ingestion pathway, as discussed in Section II and in derivation of the RSC. Dermal absorption is relatively low for this heavy metal, and in general, inhalation is considered to contribute less than 2% of total intake even when environmental ambient air exposures are considered.

Livestock watering and produce irrigation will result in primarily dietary ingestion of uranium transferred to plant and animal tissues. In derivation of the RSC, a source contribution of 0.3 was allowed for food sources, 10% greater than that used in derivation of the EPA standard. This is because New Mexican populations frequently consume a substantial portion of their diet from foods grown or obtained locally, and New Mexico is a highly mineralized area with respect to uranium ore bodies. However, as identified in Section II, absorption of uranium ingested in food is relatively low when compared to uranium ingested in water. Using the RSC of 0.3 for intake from food, should therefore be protective of intake via that source even if that food has an increased uranium content from water transfer.

Because absorption of uranium from water ingestion is substantially greater than from other sources, basing calculations of a ground water standard on the intake from drinking water, assuming a 0.7 RSC should provide the most protective basis for this calculation across all uses of ground water.

#### ***V.B. Derivation Based on Nephrotoxicity.***

***V.B.1. Dose-Response.*** Dose-response data for kidney toxicity from exposure to natural uranium is incomplete for humans and insufficient for establishment of a no-observed adverse effect level (NOAEL). However, there are conclusive toxicity data defining the lowest-observed-adverse-effect level (LOAEL) in non-human animal studies. These data will be the basis for derivation of a health-protective recommended ground water standard for uranium based on kidney toxicity. As discussed in Section III, toxicity to the proximal tubules of the kidney has been observed at exposure (intake) doses as low as 50 µg/kg-day in rabbits (Gilman et al., 1998b) and 60 µg/kg-day in rats (Gilman et al. 1998a). The 91-day study of uranium intake (as uranyl nitrate hexahydrate) from drinking water revealed histological changes in the renal tubules of male Sprague-Dawley rats at a subchronic LOAEL of 60 µg/kg-day. Renal lesions of tubules included apical displacement and vesiculation of tubular nuclei, cytoplasmic vacuolation,

dilation, and degranulation. In this study, males showed a greater response than females at the same dose level, i.e., males were more sensitive to the toxic effects. No dose-response relationship could be demonstrated with increasing doses for either gender.

A similar LOAEL of 50 µg/kg-day was derived from the 91-day study in male New Zealand White rabbits administered uranium nitrate in their drinking water (Gilman et al., 1998b). Male rabbits exhibited a statistically significant increase in the incidence of lesions to renal tubules manifested as cytoplasmic vacuolation, anisokaryosis and nuclear vesiculation.

Although adverse effects were observed at lower levels in rabbits than in rats, the rat study was used to select safe exposure doses because (i) uranium produced more definitive histopathological changes than in the rabbit study; (ii) some rabbits developed *Pasteurella multocida* infections during the study, which may have affected kidney histology; and (iii) in a follow-up study with smaller sample sizes and pathogen-free animals, kidney toxicity was observed at higher uranium exposure doses than in this study (Gilman et al., 1998c). Therefore the rat study provides more definitive estimates of the lowest exposure dose producing kidney toxicity in non-human animals. However, as noted in Section II, absorption of a given dose in rats can substantially underestimate absorption in humans. Therefore, extrapolation of these rat data to derive health-protective standards for humans will need to account for this uncertainty.

Human population data have identified subclinical markers of damage to the proximal tubule of the kidney at estimated uranium exposure doses in the range of 0.004 to 9 µg/kg-day (Limson-Zamora et al., 1998). These data are consistent with kidney toxicity in non-human animals resulting from low-level exposure to uranium in drinking water, and with an anticipated greater absorption of a given exposure dose in humans which would produce toxicity at a lower exposure level. Therefore, the recommended uranium health-based ground water standard will be based primarily on the Gilman et al. rat study (1998a) with appropriate uncertainty factors incorporated.

V.B.2. Calculation. Although subject to many uncertainties, the exposure dose approach is commonly used for deriving health-based contaminant concentrations in drinking water (EPA, 1991). With this approach, observed doses from either human or non-human animal data representing NOAELs if available, and if not, LOAELs, are used as target exposure concentrations. The logic is to derive an exposure concentration where lifetime ingestion, using defined exposure assumptions, will not present an appreciable risk of adverse effects in human populations, including sensitive subgroups. The identified allowable exposure concentration will be modified to account for uncertainties such as extrapolation from non-human animal data to human populations, extrapolation from an observed LOAEL to an undetermined NOAEL, protection of sensitive subpopulations, and response variability across individuals. Generally, the EPA established convention has been to reduce the target dose by as much as an order of magnitude for each of the applicable uncertainties in these categories, with professional judgment of the level of uncertainty determining the exact number for the uncertainty factor. In addition, a modifying factor ranging from 1 to 10 is sometimes applied to reflect uncertainties in the quality of the data set used as the basis of the allowable target dose.

For the identified LOAEL of 60 µg/kg-day in rats from the Gilman et al. (1998a) data, the following uncertainties apply:

- Extrapolation from rats to humans – although the observed toxic end point is the same in both species, this uncertainty is especially relevant in light of up to 7-fold greater

absorption observed in primates compared to rodents, and associated reference to the primate being a better model of human absorption. Because of the magnitude of the absorption difference, an uncertainty factor of 5 will be applied.

- Extrapolation from subchronic to lifetime exposures – the Gilman et al. data are based on 91 day exposures. As discussed in the text, there are concerns that the subclinical effects observed in the human population would increase in severity with longer duration exposures. No obvious age-related effects were identified in the Canadian population studies, although they might be expected if chronic exposure increased effect-severity. However, the data set is not sufficient to conclusively address this question as only two elderly individuals were included, and specific data on duration of residence were not provided. However, as no obvious relationship to age was apparent in those studies, less weight will be placed on this uncertainty. A factor of 2 will be applied.
- Protection of sensitive subpopulations – i.e. those with kidney damage, elderly, and children. A factor of 10 is used because of the high incidence and prevalence of kidney disease in New Mexico's Hispanic and Native American populations. No data are currently available to assess the impact of exposure to kidney toxicants on diabetic populations already exhibiting compromised renal function. The nephropathy associated with diabetes is generally to the glomeruli, and although uranium toxicity is generally associated with the tubules, some glomerular toxicity has been observed. Because of the widespread nature of this potential sensitivity and the colocalization of these populations with areas of uranium ore deposits, an uncertainty factor of 10 will be applied.
- Extrapolation from LOAEL to a NOAEL. Less weight is given to this uncertainty. The exposure level related to the more sensitive males is used for the LOAEL, and although some the human population studies indicate subclinical effects occur at very low exposure levels, the clinical significance of those effects is uncertain. Therefore, while some correction is warranted, a factor of 2 is considered sufficient when considered along with the other uncertainties in the data.

The following equation will be used in derivation of the recommended health-protective standard:

$$C_w = \frac{LOAEL \times BW \times RSC}{UF \times IR}$$

Where:

$C_w$  = health-based standard protective of ground water ( $\mu\text{g/L}$ )  
 LOAEL = lowest-observed-adverse-effect level = 60  $\mu\text{g/kg-day}$  from the rat study by Gilman and co-workers (1998a)  
 BW = body weight: kg; 70 kg for an adult. (A protective level for children is not derived, but considered in the inclusion of the uncertainty factor of 10 for sensitive populations.)  
 RSC = relative source contribution from water = 0.7.  
 UF = uncertainty factor = 200 ( $5 * 2 * 10 * 2$ , see explanation in preceding paragraph)

IR = tap water ingestion rate = 2.4 L/day for an adult in New Mexico will be calculated, as well as the current EPA default water ingestion rate of 2 L/day. The higher 2.4 L/day value, the upper end of documented exposures utilized by EPA, is used to incorporate higher water consumption in New Mexico's desert environment.

**Adult**

Water Ingestion Rate Assumption	Calculation	Health-based Level of Uranium in Ground Water
NM-specific	$\frac{60 \mu\text{g} / \text{kg} \cdot \text{d} \times 70 \text{kg} \times 0.7}{200 \times 2.4 \text{L} / \text{d}}$	6.4 $\mu\text{g} / \text{L}$
EPA default	$\frac{60 \mu\text{g} / \text{kg} \cdot \text{d} \times 70 \text{kg} \times 0.7}{200 \times 2 \text{L} / \text{d}}$	7.3 $\mu\text{g} / \text{L}$

**V.C. Recommendation**

Based on our review of relevant technical information and data available at this time, the calculations provided, and the uncertainties discussed, a recommended standard of 7  $\mu\text{g}$  of uranium per liter of water is recommended to be protective of kidney toxicity in New Mexico populations.

# EXHIBIT P



Contents

- I.A. REFERENCE DOSE FOR CHRONIC ORAL EXPOSURE (RfD)
- I.B. REFERENCE CONCENTRATION FOR CHRONIC INHALATION EXPOSURE (RfC)
- II. CARCINOGENICITY ASSESSMENT FOR LIFETIME EXPOSURE
- VI. BIBLIOGRAPHY
- VII. REVISION HISTORY
- VIII. SYNONYMS

0421  
Uranium, soluble salts; no CASRN

Health assessment information on a chemical substance is included in IRIS only after a comprehensive review of chronic toxicity data by U.S. EPA health scientists from several Program Offices and the Office of Research and Development. The summaries presented in Sections I and II represent a consensus reached in the review process. Background information and explanations of the methods used to derive the values given in IRIS are provided in the Background Documents.

STATUS OF DATA FOR Uranium, soluble salts

File On-Line 10/01/1989

Category (section)	Status	Last Revised
Oral RfD Assessment (I.A.)	on-line	10/01/1989
Inhalation RfC Assessment (I.B.)	no data	

Attachment  
A

Carcinogenicity Assessment (II.)

no data

**I. CHRONIC HEALTH HAZARD ASSESSMENTS FOR NONCARCINOGENIC EFFECTS**

**I.A. REFERENCE DOSE FOR CHRONIC ORAL EXPOSURE (RfD)**

Substance Name -- Uranium, soluble salts  
 CASRN --  
 Last Revised -- 10/01/1989

The oral Reference Dose (RfD) is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. It is expressed in units of mg/kg-day. In general, the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Please refer to the Background Document for an elaboration of these concepts. RfDs can also be derived for the noncarcinogenic health effects of substances that are also carcinogens. Therefore, it is essential to refer to other sources of information concerning the carcinogenicity of this substance. If the U.S. EPA has evaluated this substance for potential human carcinogenicity, a summary of that evaluation will be contained in Section II of this file.

**I.A.1. ORAL RfD SUMMARY**

Critical Effect	Experimental Doses*	UF	MF	RfD
Initial body weight loss; moderate nephrotoxicity	NOAEL: None	1000	1	3E-3 mg/kg/day
30-Day Oral Rabbit Bioassay (diet)	LOAEL: 0.02 ppm uranyl nitrate hexahydrate in food (converted to 2.8 mg uranium/kg/day			

Maynard and Hodge, 1949

\*Conversion Factors: Test compound is 47% uranium by weight (molecular weight ratio 238/502). 1 ppm = 0.03 mg/kg/day (assumed rabbit food consumption).

## I.A.2. PRINCIPAL AND SUPPORTING STUDIES (ORAL RFD)

Maynard, E.A. and H.C. Hodge. 1949. Studies of the toxicity of various uranium compounds when fed to experimental animals. In: *The Pharmacology and Toxicology of Uranium Compounds*. Nations Nuclear Energy Service. Division VI, Vol. I. C. Voegtlin, and H.C. Hodge, Eds. McGraw Hill, New York, NY. p. 309-376.

Rabbits, rats and dogs were administered uranium compounds in the diet for 30 days. Studies of rats and dogs were continued for longer periods with serial sacrifices up to 1 year (rats and dogs) or 2 years (rats only) of exposure. Rabbits showed greater sensitivity to the toxic effects of uranium. Rabbits (6/group; strain and sex not reported) were fed dietary levels of uranyl nitrate hexahydrate of 0, 0.02, 0.1, or 0.5% for 30 days (equivalent to doses of 2.8, 14, and 71 mg U/kg/day). Animals were examined daily, body weights were recorded weekly and kidneys were examined histologically at the termination of the experiment. Mortality was observed at the two highest doses (6 of 6 fed 71 mg U/kg/day, 4 of 6 fed 14 mg U/kg/day). During the first week of exposure, body weight losses were observed at all doses. After 30 days exposure, body weights of rabbits receiving 2.8 mg U/kg/day were similar to controls. Renal damage was judged to be moderate at the two lower doses and moderately severe at the highest dose. Based on this study, the lowest dose tested in rabbits (2.8 mg U/kg/day) was judged to be the LOEL.

The toxicity of uranium compounds was less severe to rats and dogs, although water soluble uranium compounds (UO<sub>2</sub>F<sub>2</sub>, UO<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub>, UCl<sub>4</sub>) were more toxic than insoluble compounds (Maynard and Hodge, 1949). LOELs for these compounds were 39, 120, and 160 mg U/kg/day for rats, and 7.7, 9.5, and 132 mg U/kg/day for dogs, respectively. In most cases, LOELs could be identified within the first 30 days of exposure.

Uranium is a classical nephrotoxic. The toxicity of this chemical to humans has been of interest since the 1800's when uranium was used as a homeopathic cure for diabetes mellitus (Hodge, 1973). These early reports demonstrate the susceptibility of humans to the nephrotoxicity of ingested uranium, but provide inadequate basis for estimating the threshold dose for toxic effects.

Hursh et al. (1969) administered single oral doses of uranyl nitrate (10.8 mg U/ 65 to 170 ug U/kg) to four hospital patients. Urinary levels of uranium and protein were determined. Urinary protein was not elevated in any of the patients.

Humans have been exposed to uranium compounds by intravenous injection in controlled experiments on uranium excretion and toxicity (Hursh and Spoor, 1973; Lussenhop et al., 1958). Single doses of 120 ug U/kg and higher administered to terminal brain tumor patients were associated with elevations in urinary excretion of catalase, albumin and non-protein nitrogen, and casts in the urine (Lussenhop et al., 1958). Hursh and Spoor (1973) describe a study in which seven patients were injected with uranyl nitrate (6.3, 6.3, 16, 30, 42, 55, or 71 ug U/kg). Renal function tests were performed including urinary catalase, protein, nitrogen, glomerular filtration rate, maximum tubular excretory capacity and urea clearance. Trace changes in urinary catalase were noted in patients receiving 55 or 71 ug U/kg.

Novikov and Yudina (1970) administered female rabbits (6 to 8/group) oral doses of uranyl nitrate of 0, 0.02, 0.2, and 1 mg U/kg/day for 12 months. No differences were noted compared with controls with respect to serum urea, creatinine or chlorides. Further experiments on enzyme levels in tissue homogenates were equivocal; enzyme activities were only expressed relative to the wet weight of the tissue from which the homogenate was prepared.

Limited data are available on the reproductive toxicity of uranium. Maynard

and Hodge (1949) conducted a 2-year study of the reproductive effects of uranium. Administration of dietary levels of uranyl nitrate of 2% (equivalent to a dose of approximately 470 mg U/kg/day) resulted in decreased food consumption, and declines in weight gain. Decreases in the number of litters born, litter size, were consistent with the decline in nutritional status of the animals.

In a second study by Maynard and Hodge (1949), rats (50/sex) were exposed to dietary levels of uranyl nitrate of 2% (about 460 mg/kg) for one day. Males and females were then paired, over a period of 7 months. Declines in total number of pups born (1959 vs. 1725; 12% decrease) and litter size (8.6 vs. 7.6; 7% decrease) were observed with treatment, but the actual number of litter bearing females increased from 43/50 to 44/50 with treatment.

### I.A.3. UNCERTAINTY AND MODIFYING FACTORS (ORAL RfD)

UF -- The UF of 1000 reflects 10 for both intraspecies and interspecies variability to the toxicity of the chemical in lieu of specific data, and 10 for use with a LOAEL from an animal study. The uncertainty factor does not include an extra factor of 10 for less-than-lifetime exposure since experiments of acute/subacute duration have been shown to be adequately sensitive for determining doses which cause chronic nephrotoxicity. Rabbits inhaling uranyl nitrate dust (0.25 mg/cu.m) for 10 days showed similar, nephrotoxic effects (interstitial nephritis, tubular regeneration) compared with rabbits exposed to these levels for 6.5 months (Stokinger et al., 1949). Similarly, rats and dogs ingesting uranium compounds displayed similar NOAELs/LOAELs after 30 days exposure compared with exposures of 1 or 2 years (Maynard and Hodge, 1949).

MF -- None

### I.A.4. ADDITIONAL COMMENTS (ORAL RfD)

Pharmacokinetic models were considered in developing the RfD. Although parameters for absorption, distribution, and accumulation in the kidney are uncertain, reasonable risks can be estimated for these parameters. However, data are inadequate for determining a threshold for uranium levels in the kidney which cause nephrotoxicity and it is questionable whether total uranium levels in the kidney are a good measure of the potential for toxicity. Because of these uncertainties, modeling approaches were not used to determine the RfD.

### I.A.5. CONFIDENCE IN THE ORAL RfD

Study -- Medium  
Data Base -- Medium  
RfD -- Medium

The critical study is well designed, but used a small number of experimental

animals; it rates medium confidence. The data base is given a medium level of confidence since there are adequate studies on the effects of U in various species. Medium confidence in the RfD follows.

#### I.A.6. EPA DOCUMENTATION AND REVIEW OF THE ORAL RfD

Source Document -- U.S. EPA, 1985

Other EPA Documentation -- None

Agency Work Group Review -- 01/19/1989

Verification Date -- 01/19/1989

#### I.A.7. EPA CONTACTS (ORAL RfD)

Please contact the Risk Information Hotline for all questions concerning this assessment or IRIS, in general, at (513)569-7254 (phone), (513)569-7159 (FAX) or RIH.IRIS@EPAMAIL.EPA.GOV (internet address).

---

#### I.B. REFERENCE CONCENTRATION FOR CHRONIC INHALATION EXPOSURE (RfC)

Substance Name -- Uranium, soluble salts  
CASRN --

Not available at this time.

---

#### II. CARCINOGENICITY ASSESSMENT FOR LIFETIME EXPOSURE

Substance Name -- Uranium, soluble salts  
CASRN --

This substance/agent has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential.

---

## VI. BIBLIOGRAPHY

Substance Name -- Uranium, soluble salts  
CASRN --  
Last Revised -- 10/01/1989

### VI.A. ORAL RFD REFERENCES

- Hodge, H. 1973. A History of Uranium Poisoning 1824-1942. In: Uranium, Plutonium, Transplutonic Elements, H.C. Hodge, J.N. Stannard and J.B. Hursh, Ed. Springer-Verlag, New York. p. 1-60.
- Hursh, J.B. and N.L. Spoor. 1973. Data on Man. In: Uranium, Plutonium, Transplutonium Elements, H.C. Hodge, J.N. Stannard and J.B. Hursh, Ed. Springer-Verlag, Berlin. p. 197-239.
- Hursh, J.B., W.R. Neuman, T. Toribara, H. Wilson and C. Waterhouse. 1969. Oral ingestion of uranium by man. *Health Phys.* 17: 619-621.
- Lussenhop, A.J., J.C. Gallimore, W.H. Sweet, E.G. Struxness and J. Robinson. 1956. The toxicity in man of hexavalent uranium following intravenous administration. *Am. J. Roent.* 79(1): 83-100.
- Maynard, E.A. and H.C. Hodge. 1949. Studies of the toxicity of various uranium compounds when fed to experimental animals. In: *The Pharmacology and Toxicology of Uranium Compounds*. Nations Nuclear Energy Service. Division VI, Vol. I, C. Voegtlin and H.C. Hodge, Ed. McGraw Hill, New York, NY. p. 309-376.
- Novikov, Y.V. and T.V. Yudina. 1970. Data on the biological effect of small amounts of natural uranium in water. *Hyg. Sanit.* 35: 225-261.
- Stokinger, H.E., R.C. Baxter, H.P. Dygert, C.W. LaSelle, S. Lasin, et al. 1949. Toxicity following inhalation for 1 and 2 years. In: *The Pharmacology and Toxicology of Uranium Compounds*. Nations Nuclear Energy Service. Division VI, Vol. I, C. Voegtlin and H.C. Hodge, Ed. McGraw Hill, New York, NY. p. 1370-1778.
- U.S. EPA. 1985. Drinking Water Criteria Document for Uranium. Office of Drinking Water, Washington, DC. (Draft)
-

VI.B. INHALATION RfD REFERENCES

None

---

VI.C. CARCINOGENICITY ASSESSMENT REFERENCES

None

---

VII. REVISION HISTORY

Substance Name -- Uranium, soluble salts  
 CASRN --

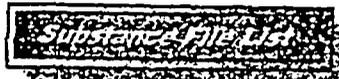
Date	Section	Description
10/01/1989	I.A.	Oral RfD summary on-line
10/01/1989	VI.	Bibliography on-line
01/01/1992	IV.	Regulatory Action section on-line

---

VIII. SYNONYMS

Substance Name -- Uranium, soluble salts  
 CASRN --  
 Last Revised -- 10/01/1989

Uranium (soluble salts)



Send  
Comments



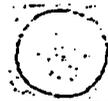
Search



NCEA  
Home Page



ORD  
Home Page



EPA  
Home Page

Last updated: 5 May 1998

URL: <http://www.epa.gov/iris/subst/0421.htm>

---

## EXHIBIT Q

From:  
HRI G-11-A  
water Rights  
Transfer Application;  
Protestants' Exh. 30  
March 1998

<b>NAVAJO NATION / OSE HEARING G-11-A</b>		
<b>SIMULATED LOADING OF EXISTING WELLS</b>		
<small>Date: 3/16/98</small>	<b>EXHIBIT 30</b>	
<small>Produced By: SES</small>		
<small>Checked By: WPP</small>		
<small>File Name: MODEL.app</small>		

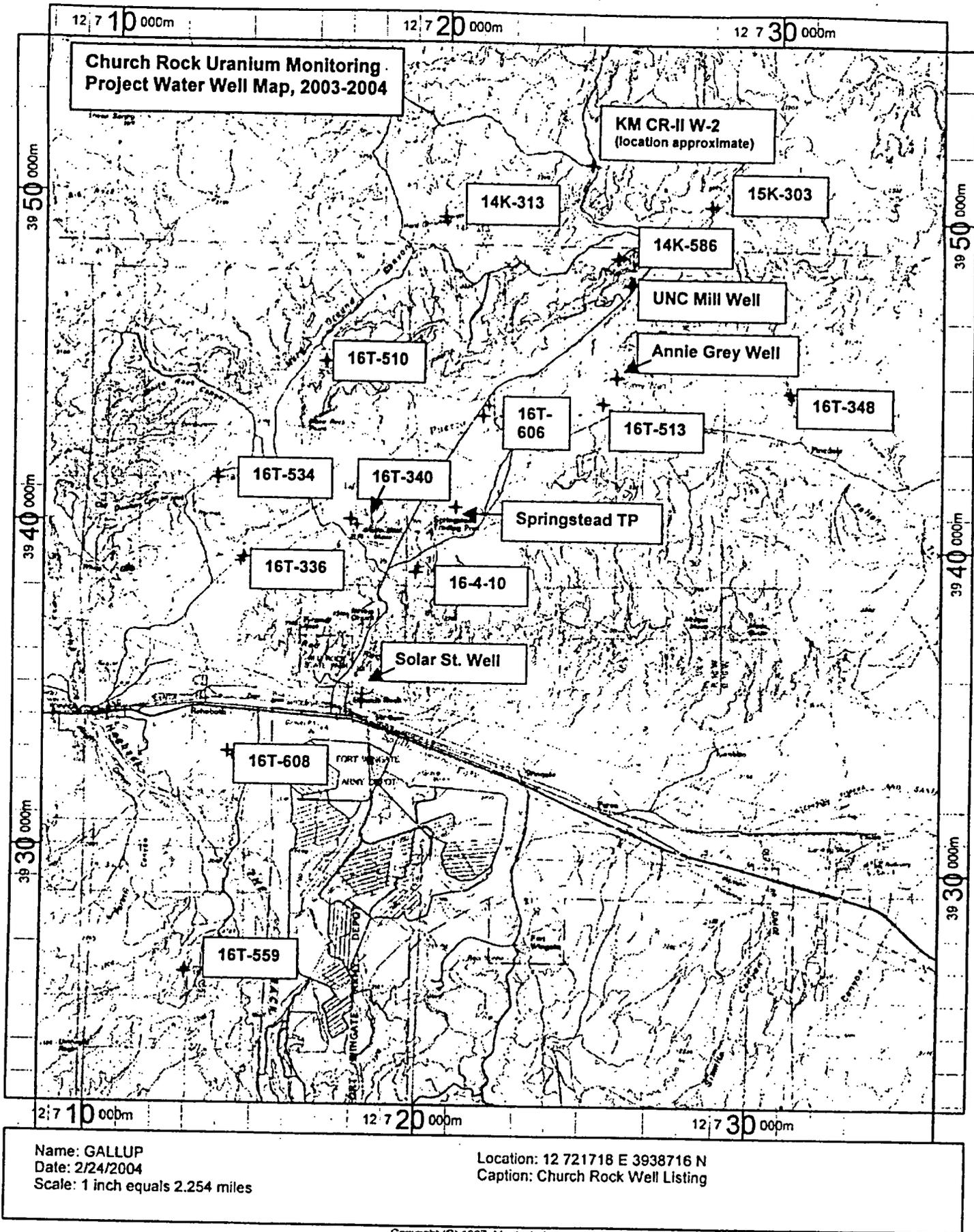
BALLEAU GROUNDWATER, INC.

**WESTWATER WELLS WITH SIMULATED 30 YEAR LOADINGS**

NUMBER	WELL NUMBER	WELL NAME	WELL USE	OPERATOR	ELEVATION (FEET ASSL)	DEPTH (FEET)	STATIC WATER LEVEL (FEET)	DATE	MODEL ROW_COL	30 YEAR WESTWATER DRAWDOWN (FEET)	DRAWDOWN AS PERCENTAGE OF STATIC WATER-LEVEL
1	18K-525		LIV	TRIBE O&M	7240	1221	n/a	n/a	31-42	0.9	-
2	28U-321P	17N 12W 28 1413	OTH	MOBIL OIL	6818	2108	n/a	n/a	24-40	2.3	-
3	PATH 320	17N R13W 32 231	OTH	PATHFINDER	7150	2000	n/a	n/a	28-37	5.0	-
4	VWC-1	17 14W 13. 114HA	OTH	NUCLEAR	8758.5	2225	n/a	n/a	25-35	7.3	-
5	BRNHM WSW1	NRO48.0400X1890	LIV	EPNG	5746	5250	n/a	n/a	9-15	0.8	-
6	BRRGO PS PM3	BORREGO PASS PM3	DOM	BIA	7300	2023	756	9/7/72	28-44	0.8	0.1
7	SMIT LAKE O3	SMITH LAKE T.P. TEST WELL	OTH	TRDG POST	7260	1100	600	11/30/72	32-42	0.8	0.1
8	15-UNK-0012	16N 10W 18 133D	OTH	CONOCO	6924	2111	424.8	4/1/83	24-45	0.8	0.2
9	18T-558		LIV	TRIBE O&M	7585	1800	790	8/5/71	28-38	3.6	0.5
10	15-UNK-0010	17N.12W.28.1413	IND	MOBIL OIL	6820	2140	371.4	6/25/85	24-40	2.3	0.6
11	LANCE BJ-2	LANCE CORP BLACKJACK -2	IND	LANCE CORP	7428	350	210	7/11/81	37-39	1.4	0.7
12	15-0581	CONOCO #2 (NTUA)	MUN	NTUA	6875	2377	443.2	6/21/83	24-39	2.9	0.7
13	15-0578	CROWNPOINT #1	MUN	NTUA	6950	2345	423	3/13/75	24-39	2.9	0.7
14	15-0580	15-UNK-0008/17N 12W 173333	OTH	CONOCO	6874	2450	349.8	12/13/75	24-39	2.9	0.8
15	PU-279	17N 13W 09 321	OTH	MOBIL OIL	6702	2080	274.2	6/28/85	24-37	4.5	1.6
16	16L-73	MOBIL 16L-73	OTH		6752	2100	293.9	8/1/83	25-37	4.8	1.6
17	94-202	17N 13W 09 3212	OTH	MOBIL OIL	6899	2120	269.7	6/28/85	24-37	4.5	1.7
18	15-UNK-0001	17N 14W 13 1144B	OTH	NUCLEAR	6757	2225	332.4	8/4/82	25-35	7.3	2.2
19	KM CR II W-2	KERR-MCGEE W-2	OTH	KERR-MCGEE	7290	2514	1370.5	4/24/80	32-23	34.0	2.5
20	18T-534	NR106.0820X1070	DOM	TRIBE O&M	6825	410	250	7/29/85	47-17	8.1	3.3
21	15-0586	STANDING ROCK #1	MUN	NTUA	6497	2688	87.3	6/7/80	24-33	8.6	9.8
22	18T-513	16N 16W 15 4322	DOM	TRIBE O&M	6875	318	182	7/27/69	40-28	42.3	23.3

**DAKOTA WELLS WITH SIMULATED 30 YEAR LOADINGS**

NUMBER	WELL NUMBER	WELL NAME	WELL USE	OPERATOR	ELEVATION (FEET AMSL)	DEPTH (FEET)	STATIC WATER LEVEL (FEET)	DATE	MODEL ROW_COL	30 YEAR DAKOTA DRAWDOWN (FEET)	DRAWDOWN AS PERCENTAGE OF STATIC WATER-LEVEL
1	18T-540	MANUELITO	DOM	TRIBE O&M	8278	400	n/a	n/a	58 - 11	0.0	-
2	HASSEL	USIS HASSEK WELL	UNK	HASSEL	7140	1000	n/a	n/a	31 - 43	0.1	-
3	TIDEWATER001	TIDEWATER OIL CO	IND	TIDEWATER	7420	494	n/a	n/a	38 - 39	0.1	-
4	18T-328	18 108-05.10X18.70	DOM	TRIBE O&M	8740	1358	n/a	n/a	55 - 7	0.1	-
5	18-0878	NA 95-795	DOM	IHS/OEHE	8330	1916	-31	9/20/88	54 - 12	0.8	-
6	18T-544	SPENCER VALLEY	DOM	TRIBE O&M	6395	1190	n/a	n/a	54 - 12	0.8	-
7	14-UNK-0004	08N 17W 06 411	LIV	BRUTON	6950	405	n/a	n/a	28 - 14	6.1	-
8	18T-588	CASAMERA LAKE	MUN	NTUA	7080	700	443	7/26/76	29 - 45	0.05	0.01
9	18T-501		LIV	TRIBE O&M	7270	995	665	8/28/59	28 - 47	0.1	0.01
10	SMIT LAKE 01	SMITH LAKE MISSION	DOM	MISSION	7250	678	355	8/8/55	33 - 42	0.1	0.02
11	18T-597	SMITH LAKE #2	MUN	NTUA	7228	1939	474.6	11/16/78	31 - 42	0.1	0.03
12	18B-37		LIV	PRIVATE	7185	812	380	n/a	28 - 44	0.1	0.04
13	18T-594	SMITH LAKE #1	MUN	NTUA	7215	2024	407	2/27/78	30 - 42	0.2	0.04
14	15-UNK-0013	16N 10W 18 133B	OTH	CONOCO	6924	1902	350.5	8/5/82	24 - 45	0.3	0.1
15	18K-318	TIDEWATER OIL CO WELL	UNK	UNKNOWN	7410	292	230	10/3/48	33 - 39	0.3	0.1
16	18T-592	16N 14W 11 2223	UNK	TRIBE O&M	7385	1400	602	5/1/77	27 - 36	1.4	0.2
17	18-0871		DOM	MANUELITO	8278	423.5	15	7/28/84	58 - 11	0.0	0.3
18	15-UNK-0009	17N.12W.28.1413	OTH	MOBIL OIL	6817	1750	219.9	5/5/82	24 - 40	0.7	0.3
19	18P-101	17N.13W.16.442	OTH	MOBIL OIL	6765	1800	123.5	8/1/83	25 - 37	1.3	1.0
20	15-UNK-0002	17N 14W 13 1144C	OTH	NUCLEAR	6757	1728	78.2	8/4/82	25 - 35	1.8	2.4
21	18T-608		LIV	TRIBE O&M	6780	417	79	7/3/80	41 - 24	3.4	4.3
22	18T-510	NOSE ROCK WELL	LIV	TRIBE O&M	6818	680	103.5	8/30/80	44 - 18	7.7	7.4



Name: GALLUP  
 Date: 2/24/2004  
 Scale: 1 inch equals 2.254 miles

Location: 12 721718 E 3938716 N  
 Caption: Church Rock Well Listing

Copyright (C) 1997, Maptech, Inc.

Base map courtesy Navajo Nation Department of Water Resources; well locations by Southwest Research & Information Center

Navajo Nation Well No.	Local Well Name	T-R-S-qqsec	Latitude	Longitude	UTM-X (East) Zone 13	UTM-Y (North) Zone 13	Navajo Nation Chapter	Elev. ASL (ft.)	NNDWR Records?	Fm	Type (Year drilled)	TD (ft.)
14K-313	Brown Bull Windmill	106-3.85x5.70; 17.16.32 or 29 (inferred)	35°39'58.392"N	108°34'06.362"W	720174	3949416	Coyote Canyon	7010	yes	Kg	windmill (1953)	622
14N-70		16.16.6					Coyote Canyon	7010	UNK	Kcd	developed spring?	
14T-586	Water Pond Rd.; "Friendship I" by KMNC	17.16.25 or 26 (inferred); 106-7.34x12.23	35°39'43'.222"N	108°30'55.785"W	724991	3949101	Coyote Canyon		yes	Kg	drilled well (1976)	750
15K-303	Pipeline Canyon Windmill	17.15.30 or 29.421; 105-12.86x5.47	35°40'16.514"N	108°28'42.011"W	728291	3950171	Nahodish gish	7038	yes	Kg	windmill (1952)	614
16-4-10	Lime Ridge hand pump	16.16.31.33	35°34'18'.611"N	108°34'37.954"W			Church Rock		no	Jmw or Qal	dug well, hand pump	
16-4-14	Silversmith hand pump	16.17.33.3412					Church Rock		no	Qal	dug well, hand pump	
16K-319		16.16.1					Pinedale	7128	UNK	Kd		963
16K-340	Windmill Cluster	16.17.25.1132	35°35'34'.336"N	108°35'53.105"W	717664	3941251	Church Rock		yes	Qal	windmill (1954)	141
16T-336	Puerco North Fok Windmill	16.17.33.4223	35°34'21'.494"N	108°38'12.086"W			Church Rock		no	Qal	windmill	122
16T-348	Lobo Valley Windmill	16.15.17.1431	35°37'178"N	108°27'195W			Pinedale	6900	UNK	Kd	windmill	410
16T-510	Nose Rock Windmill	16.17.15.242	35°37'09'.876"N	108°37'22.274"W	715269	3944092	Church Rock	6818	yes	Kd	windmill (1960)	680
16T-513	Uphill Road Windmill	16.16.15.4322	35°36'49.4496"N	108°31'00.906"W	724982	3943735	Pinedale	6875	yes	Jmw	windmill (1959)	318
16T-532	Old Church Rock Mine	16.16.17.21			721605	3944640	Church Rock	6810	yes	Kd?	windmill (ND)	450
16T-534	Superman Canyon Windmill	16.17.21.344; 106-8.20x10.70	35°35'48.727"N	108°38'40.253"W	713451	3941570	Church Rock	6825	yes	Jmw	windmill (1965)	410

## Church Rock Area Water Wells

ChurchRockWellsobm.xls

Updated 12/28/04

Navajo Nation Well No.	SWL (ft.) (date)	Yield (gom)	Water Quality Data?	Use(s)	Status (date)	Condition/Comments
14K-313	235 (1953)	20	yes	LS, DOM	OP (7/22/03) (10/29/03)	good quality; cattle present; haulers use in home; WL data from UNC Lic. Renewal Appl. (1981)
14N-70		0.5	UNK	DOM, LS	UNK	data from UNC License Renewal Application (1981), Table B3.15
14T-586	381 (1991)		yes	DOM, LS	NOP (8/5/03)	served as water source for KM Mine and homes on Water Pond Road; closed June 2003
15K-303	305 (1952) 318 (1974) 327 (1985)	23	yes	LS, DOM	OP (7/29/03) (10/28/03)	poor quality; open tank; sheep present; WL data from UNC Lic. Renewal Application (1981)
16-4-10			yes	DOM, LS	OP (8/5/03) (10/29/03)	0.25 mi. w/ Foutz#3 mine; water clear; drinker, overhead spout
16-4-14			yes	DOM, LS	UNK	next to homes; status unknown
16K-319	320 (1948)	7	UNK	DOM, LS	UNK	data from UNC License Renewal Application (1981), Table B3.15
16K-340	30.5 (1954)		yes	LS	OP (7/22/03) (10/29/03)	cattle present
16T-336	33.8 (1955)		yes	LS	OP (10/29/03)	visited 7/22/03; operational; cattle present
16T-348	87 (1974)	8	yes	LS	OP (10/29/03)	data from UNC License Renewal Application (1981), Table B3.15
16T-510	103.5 (1960)		no	LS	NOP (7/22/03)	no water in tank; connected to distant cattle drinkers; no water observed
16T-513	182 (1959) 275 (1974) 160 (1977) 308 (1980)	33	yes	LS, DOM	NOP (7/29/03)	located at intersection of Pinedale Rd. & Uphill Rd.; windmill parts working, but no water flowing; data from UNC Lic. Renewal Appl.
16T-532			no	LS	NOP/ ABND	inactive since 1964; was used for all purposes by local residents
16T-534	250 (1965) 199.1 (1984)		yes	LS, DOM	OP (7/22/03) (10/29/03)	good quality; cattle present; haulers use in home

## Church Rock Area Water Wells

ChurchRockWellsobm.xls

Updated 12/28/04

Navajo Nation Well No.	Local Well Name	T-R-S-qqsec	Latitude	Longitude	UTM-X (East) Zone 13	UTM-Y (North) Zone 13	Navajo Nation Chapter	Elev. ASL (ft.)	NNDWR Records?	Fm	Type (Year drilled)	TD (ft.)
16T-559	Coal Mine Windmill	15.17.33.43	35°27'33".612"N	108°39'12.329"W	713244	3926903	Church Rock		yes	UNK	windmill (UNK)	UNK
16T-606	King Ranch Windmill	16.16.17.411	35°36'5.773"N	108°33'14.316"W	721599	3943978	Church Rock	6780	yes	Kd	windmill (1980)	417
16T-608	John & Annie Yazzie Windmill	15.17.21.4	35°31'07".434"N	108°38'20.143"W			Church Rock				windmill	
none	Annie Grey/ Grey Family hand pump	16.16.14.1111	35°37'27".384"N	108°30'39.927"W			Pinedale			Qal	dug well, hand pump	8
none	Church Rock Solar St. hand pump	15.17.13.1	35°32'09".736"N	108°35'45.366"W			Church Rock			Qal?	drilled well; "hot spring"	UNK
UNK	Church Rock Spring	15.17.02.42					Church Rock				spring	
UNK	Hard Ground Canyon Spg.	16.17.21.44					Church Rock				spring	
none	Kerr-McGee CR-II W-2	17.16.22.432			723958	3950870	Coyote Canyon	7290	yes	Jmw	drilled well (1977)	2,514
UNK	Kit Carson Cave spring	15.17.01.22					Church Rock				spring	
none	Springstead Trading Post	16.16.30.112			175770?	3944666	Church Rock				drilled well (1968)	500
UNK	Superman Canyon Spg.	16.17.28.311					Church Rock				spring	
none	UNC Northeast Church Rock Mine	17.16.35					Pinedale	7180	UNK	Jmw-Kd	drilled well (1969)	1,650
none	UNC Mill	16.16.2.11					Pinedale			Jmw	drilled well (1976 or before)	

## Church Rock Area Water Wells

ChurchRockWellsobm.xls

Updated 12/28/04

Navajo Nation Well No.	SWL (ft.) (date)	Yield (gom)	Water Quality Data?	Use(s)	Status (date)	Condition/Comments
16T-559	UNK		yes	LS	OP (8/5/03) (10/28/03)	located on hill between parts of AMCOAL coal mine; several homes nearby
16T-606	79 (1980)		yes	LS	OP (7/22/03) (10/28/03)	on west side Old Church Rock Mine Rd. across from King Ranch
16T-608				DOM, LS	(10/28/03)	evidence of recent use; tank, drinker in good shape
none			yes	LS, DOM	OP (8/5/03) (10/28/03)	in North Fork of Puerco upstream of Piipeline Arroyo
none			yes	LS, DOM	OP (7/29/03) (10/29/03)	located n/ Chap. House in CR village; fitted w/ hand pump; not used much because low is limited
UNK			UNK		NOP	located at base of the church rock; officials say not used because difficult to reach by foot
UNK			UNK		UNK	officials say not used because difficult to reach by foot
none	1,334.9 (1985)		yes	MON	ABND?	Kerr-McGee drilled W-2 for mine-development, monitoring purposes; TNN requested W-2 be abandoned in 1995; no confirmation
UNK			UNK		UNK	behind locked gate off SR566; difficult hike on foot to cave
none			UNK	DOM	OP (6/24/03)	connected to electricity source; was water source for Springstead TP; BacT sample by FHDC in 2003; found in NMSEO records
UNK			UNK		NOP	officials say not used because of vandalism
none	900 (1969)	20	yes	DOM	UNK	well for Northeast CR Mine; data from UNC '81 license renewal application; may be same as UNC Mill well
none		24	yes	DOM, IND	OP (July 2002)	Info., data from MWH UNC-NECR Site Assessment (7/03) and Close-out Plan (1/04); may be same as NECR mine well

Church Rock Area Water Wells

ChurchRockWellsobm.xls

Updated 12/28/04

Navajo Nation Well No.	Local Well Name	T-R-S-qqsec	Latitude	Longitude	UTM-X (East) Zone 13	UTM-Y (North) Zone 13	Navajo Nation Chapter	Elev. ASL (ft.)	NNDWR Records?	Fm	Type (Year drilled)	TD (ft.)
UNK	UNK	16.16.14					Pinedale	6905		Jmw		525
UNK	UNK	16.16.16					Church Rock	6799		Qal	1968 or before	
UNK	UNK	16.16.17					Church Rock	6808		Jmw	1974 or before	

Navajo Nation Well No.	SWL (ft.) (date)	Yield (gom)	Water Quality Data?	Use(s)	Status (date)	Condition/Comments
UNK	54 (1974)		UNK	DOM, LS	UNK	data from UNC License Renewal Application (1981), Table B3.15
UNK	144 (1968)					data from UNC License Renewal Application (1981), Table B3.15
UNK	319 (1974)					data from UNC License Renewal Application (1981), Table B3.15; this well is NOT 16T-606

New Mexico Office of the State Engineer  
Well Reports and Downloads

Township:  Range:  Sections:

NAD27 X:  Y:  Zone:  Search Radius:

County:  Basin:  Number:  Suffix:

Owner Name: (First)  (Last)   Non-Domestic  Domestic  All

WELL / SURFACE DATA REPORT 12/14/2004

DB File Nbr	(acre ft per annum)	Use	Diversion	Owner	Well Number	Source	Tws	Rng	Sec	q	q	q	X Y are in Feet
G	01100	COM	51	WILLIAM H. AUBREY	G 01100 S-2	Shallow	16N	16W	30	1	1	2	Zone X

Record Count: 1

Remainder of Record that could not be printed from web page screen:

UTM Zone	Easting	Northing	Start Date	Finish Date	Depth Well (in feet)
13	175770	3944666	12/31/1968	12/31/1968	500

**EXHIBIT R**

EXECUTIVE SUMMARY AND RECOMMENDATIONS  
RADIONUCLIDE LEVELS IN CATTLE RAISED NEAR URANIUM MINES  
AND MILLS IN NORTHWEST NEW MEXICO

ENVIRONMENTAL IMPROVEMENT DIVISION  
P. O. Box 968, Santa Fe, New Mexico 87504-0968

June 1986

This Study Was Funded by An Appropriation From  
The 1983 New Mexico Legislature.

## EXECUTIVE SUMMARY

Evidence from two separate studies conducted in New Mexico in 1978-1979 indicated that livestock raised near uranium mines and mills have elevated radionuclide levels, compared with controls. New Mexico's Grants Mineral Belt region covers 4,000 square kilometers and is rich in underground uranium. This area has been heavily mined for 30 years. The problem of potential livestock contamination from the uranium industry is, therefore, of great concern to the New Mexico Environmental Improvement Division (NMEID).

In 1982, the New Mexico Legislature appropriated over \$90,000 to investigate this potential problem. The present investigation was conducted to determine whether cattle grazing in areas with uranium mining and milling activity have higher levels of U-238 decay chain radionuclides than controls, and to assess the potential public health risk to humans from eating cattle raised in these areas.

Ambrosia Lake and Church Rock, NM, were chosen as areas for the study. Ambrosia Lake has been the site of extensive underground uranium mining for about 30 years and two large uranium mill tailings piles are located there. Church Rock was chosen because of concerns generated by a study conducted in this community following an accidental spill of mill tailings effluent in 1978. Crownpoint, an area 40 kilometers northwest of Ambrosia Lake, has not been developed for uranium mining or milling and was chosen as a suitable control site.

Cattle were purchased from the above study areas. Five cattle were purchased from one owner in Ambrosia Lake (ALG1); five from another owner (ALG2); seven from Church Rock (CR); and ten from Crownpoint (CP). On the basis of previous studies by the NMEID of the uranium mining and milling activities in these areas, it was determined that the cattle's potential for ingestion of radio nuclides was highest in Ambrosia Lake, followed by CR. The CP animals were not exposed to the uranium activities and were used as a comparison group.

The twenty-seven cattle were slaughtered in October, 1983. Muscle, liver, kidney, and femur were analyzed for uranium-238 (U-238), uranium-234 (U-234), thorium-230 (Th-230), radium-226 (Ra-226), lead-210 (Pb-210), and polonium-210 (Po-210) by Eberline Laboratory, Albuquerque, NM. Duplicate tissues for 20% of the cattle muscle, liver, and kidney samples were analyzed by the USEPA Las Vegas radiochemistry laboratory. In addition, samples of vegetation, soil, and water collected from each of the four groups were analyzed by Eberline for the same radionuclides. The mean radionuclide levels for the four groups were compared statistically using analysis of variance and nonparametric tests.

The laboratory analyses were completed on March 15, 1985. The mean radionuclide concentrations were highest in the ALG1 cattle followed by ALG2 and Church Rock cattle, in that order. Radionuclide levels were lowest among the control cattle.

Radium-226 and Po-210 concentrations in muscle tissue from ALG1 were higher than those in controls. Many of the radionuclide concentrations in the liver, kidneys, and femurs of AGL1 cattle were statistically higher than controls. Liver and kidney tissues from ALG1 cattle were particularly elevated in Ra-226 and Po-210. Environmental sampling of ALG1 revealed soil radionuclide levels

that were all statistically higher than controls. Vegetation from ALG1 contained significantly higher levels of Th-230 and Ra-226 than controls. Water samples contained higher levels of U-238 and U-234 than controls.

Cattle from ALG2 also had elevated radionuclide levels compared with controls. Liver was elevated in uranium and kidney was elevated in all radionuclides except Po-210. Vegetation from ALG2 contained higher levels of Th-230 and Ra-226 than controls. Mean radionuclide concentrations in soil from ALG2 were several times higher than those of controls but the differences did not attain statistical significance. Radionuclide concentrations in water samples from ALG2 were similar to those of controls except that one sample from the outflow of an ion exchange facility was elevated in uranium.

Church Rock cattle had statistically higher levels than controls of U-238 (liver and femur), U-234 (muscle, liver, and femur), and Ra-226 (femur). Soil samples from CR were higher than controls for all radionuclides tested, but the differences did not attain statistical significance. Water from CR contained concentrations of U-238 and U-234 that were statistically higher than controls.

The mean concentrations of radionuclides in muscle, liver, and kidney from each of the four groups were used to calculate 50 year radiation dose commitments and cancer risks incurred from regularly eating tissues for one year according to the following scenarios:

- scenario 1      74 kg muscle, 2.7 kg liver and 1.3 kg kidney (consumption of 78 kg of meat per year, the U.S. per capita annual average meat consumption, and muscle, liver, and kidney in proportion to the organ's percentage weight in edible beef).
- scenario 2.      78 kg of muscle and no liver or kidney
- scenario 3.      62.3 kg muscle, 13.1 kg liver, and 2.6 kg kidney (a "worst case" scenario calculated using a recent dietary survey of New Mexicans (24)).

Calculations revealed that for scenario 1, radiation doses from eating cattle tissues were similar for the CR and CP groups. Consumption of ALG2 cattle resulted in radiation doses approximately twice those incurred from eating control cattle tissues. The dose to kidney from eating ALG1 cattle was higher than the CP control by about 100 millirem. The increased lifetime risk of dying from a radiation-induced cancer from consuming ALG1 cattle for one year was one chance in 280,000.

Worst case estimates as described in scenario 3 predicted much higher doses, especially from eating ALG1 cattle. Worst case cancer risk estimates were one chance in 630,000 for control beef, one chance in 120,000 for ALG1, one chance in 400,000 for ALG2 and one chance in 670,000 for Church Rock.

Although the study has the limitations of small sample sizes and potential inaccuracies inherent to laboratory measurements of tissue radionuclide levels, it is apparent that there were elevated radionuclide concentrations in cattle tissue from all of the exposed groups. Results of environmental sampling support the conclusion that the levels of radionuclides increased as the level of exposure to the products of the uranium mining and milling industry increased.

The magnitude of the public health risk from eating this tissue is directly proportional to the amount of tissue consumed and the duration of the exposure. Eating liver and kidney incurs higher internal radiation doses than eating muscle tissue. Since few individuals would continually consume cattle raised in these areas, the risk to the general public is minimal unless an individual buys and slaughters a cow from ALG1, freezes it, and consumes large quantities of this meat.

Ranchers who raise and regularly consume these cattle (especially ALG1 cattle) may be receiving radiation doses that are excessive. The International Commission on Radiological Protection has recommended that the acceptable limit for excess deaths in a population is below one death per 100,000 exposed individuals (22). The cancer risk for a hypothetical rancher who eats ALG1 cattle for 20 years is one death per 14,000 exposed persons using scenario 1 assumptions. Thus, under these circumstances persons eating ALG1 cattle would receive an excess amount of radiation. For comparison, it was estimated by the Environmental Protection Agency that an individual who lived continuously next to some uranium mill tailings piles may have an excess lifetime cancer risk as high as 4 chances in a hundred (28). A person not exposed to uranium mining or milling activities in any way except by eating ALG1 beef for life (60 years) is subject to an additional lifetime cancer risk of about 1 in 4500, assuming scenario 1 conditions.

In conclusion, cattle from Ambrosia Lake and Church Rock had higher tissue radionuclide concentrations than controls. Evidence indicates that this resulted from exposure to radionuclides released by the uranium mining and milling industry. The public health risk from eating exposed cattle is minimal unless large amounts of this tissue, especially liver and kidney, are ingested. Radionuclide levels in ALG1 cattle were particularly high, which raises concerns about the future use of this pasture for grazing cattle.

# EXHIBIT S

Radionuclide Levels In Sheep and Cattle Grazing  
Near Uranium Mining and Milling At Church Rock, NM.

Dr. JERE B. MILLARD

Dr. SANDRA C. LAPHAM

PAUL HAHN

OCTOBER 1986

NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION

P. O. Box 968

Santa Fe, New Mexico 87504-0968

## EXECUTIVE SUMMARY

On July 16, 1979 an earthen dam holding a uranium mill tailings pond near Church Rock, New Mexico was breached, releasing 94 million gallons of acidified liquids and 1100 tons of solids. Concerns about adverse health effects to nearby human populations consuming local grazing animals, prompted an investigation by the New Mexico Environmental Improvement Division, Navajo Area Indian Health Service and the Environmental Protection Agency Office of Radiation Programs in Las Vegas, Nevada (EPA-LV).

Muscle, liver and kidney samples were collected from 10 sheep and seven cattle grazing in the Church Rock area. In addition, tissues were collected from 10 sheep and 10 cattle grazing in a control location near Crownpoint, New Mexico. Environmental samples of water, soil and vegetation were also collected from the control and Church Rock grazing areas. Sheep and cattle tissues were sent for radiochemical analyses of U-238, U-234, Th-230, Pb-210, and Po-210 at EPA Las Vegas and Eberline respectively.

Radionuclide concentrations in sheep and cattle were found to be statistically higher than control animal concentrations for U-234 and U-238 in most tissues sampled. This finding corresponded to higher observed levels of U-234 and U-238 in water samples from the Church Rock area as compared to control samples. Other radionuclides sampled from Church Rock tissues showed concentrations similar to control tissue concentrations.

Fifty-year radiation dose commitments were calculated for a hypothetical individual consuming exposed and control animal tissues. Despite elevated U-234 and U-238 tissue levels, the resulting dose commitments for Church Rock tissue consumption were very similar to those calculated for consumption of control tissues. Excess cancer risks attributable to eating exposed animal tissues from the Church Rock area were found to be negligible and below the limit of one excess cancer death per 100,000 individuals established by the International Commission on Radiological Protection.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS-----	i
EXECUTIVE SUMMARY-----	ii
INTRODUCTION-----	1
METHODS-----	3
Study Site Selection-----	3
Animal Selection and Tissue Sampling-----	4
Environmental Sampling-----	5
Laboratory Methods-----	6
Statistical Methods-----	8
Dose Commitment Calculations-----	9
Risk Estimates-----	10
RESULTS AND DISCUSSION-----	11
Limitations-----	11
Demographic and Health Data-----	12
Environmental Samples-----	12
Tissue Concentrations-----	13
Fifty Year Dose Commitments-----	18
Risk Assessment-----	21
REFERENCES-----	22

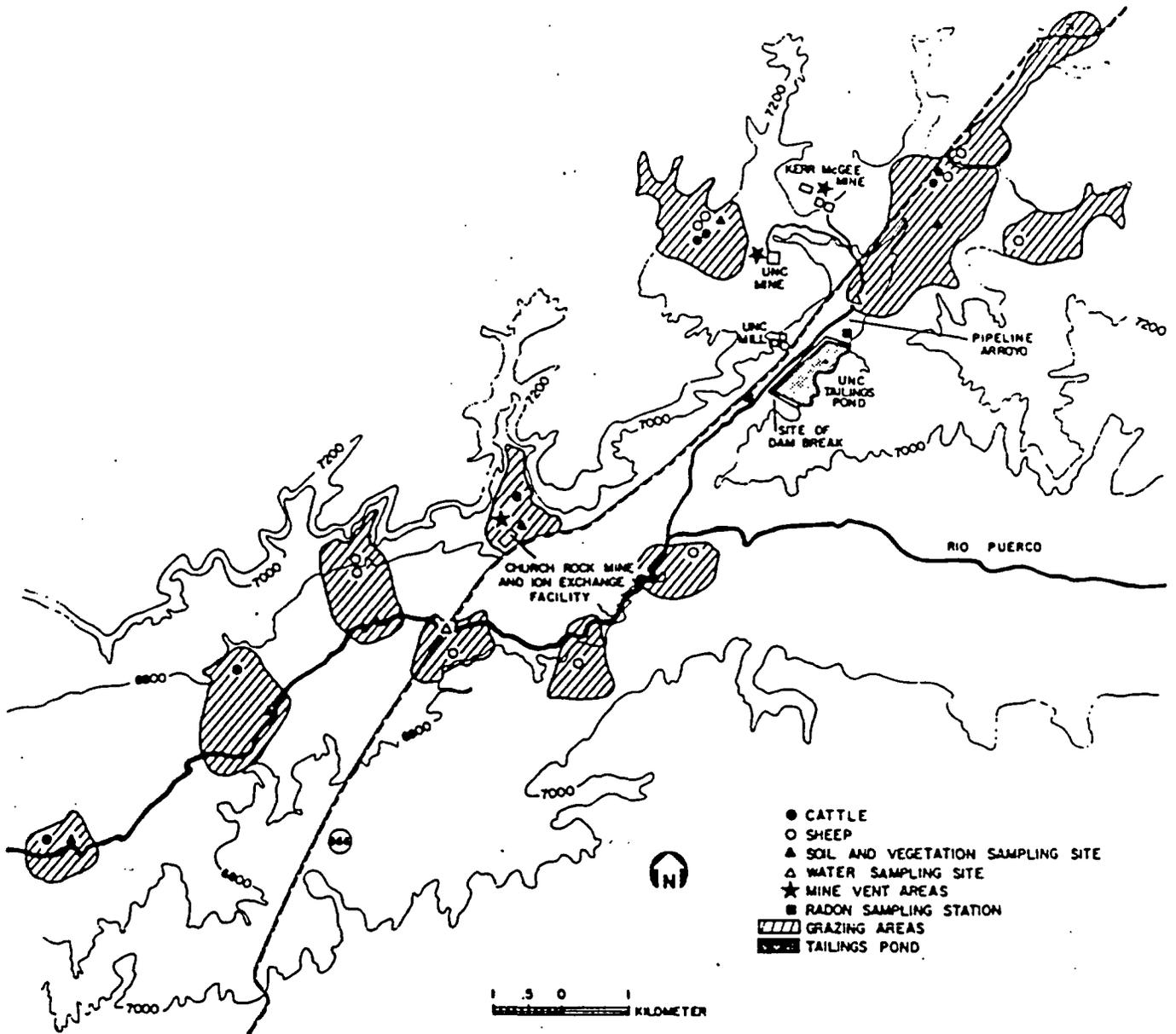


Figure 1. Church Rock animal grazing and environmental sampling locations.

# EXHIBIT T

● Paper

## HEALTH IMPLICATIONS OF RADIONUCLIDE LEVELS IN CATTLE RAISED NEAR U MINING AND MILLING FACILITIES IN AMBROSIA LAKE, NEW MEXICO

Sandra C. Lapham, M.D., M.P.H.\* and Jere B. Millard, Ph.D.†  
Environmental Improvement Division, New Mexico Health and Environment Dept.,  
P.O. Box 968, Santa Fe, NM 87504-0968

and

Jonathan M. Samet, M.D., M.S.  
University of New Mexico School of Medicine, Tumor Registry,  
900 Camino de Salud, Albuquerque, NM 87131

(Received 14 October 1987; accepted 7 October 1988)

**Abstract**—This study was conducted to determine radionuclide tissue levels in cattle raised near U mining and milling facilities. Ambrosia Lake, New Mexico, has been the site of extensive U mining for 30 y and contains several underground U mines, a processing mill, and two large U tailings piles. Ten cows were purchased from two grazing areas in Ambrosia Lake and ten control animals were purchased from Crownpoint, New Mexico.

Muscle, liver, kidney, and bone tissue taken from these animals, and environmental samples, including water, grasses and soil collected from the animals' grazing areas, were analyzed for  $^{238}\text{U}$ ,  $^{234}\text{U}$ ,  $^{230}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$ , and  $^{210}\text{Po}$ .

Mean radionuclide levels in cattle tissue and environmental samples from Ambrosia Lake were higher in almost every comparison than those found in respective controls. Liver and kidney tissues were particularly elevated in  $^{226}\text{Ra}$  and  $^{210}\text{Po}$ . Radiation dose commitments from eating cattle tissue with these radionuclide concentrations were calculated. We concluded that the health risk to the public from eating exposed cattle is minimal, unless large amounts of this tissue, especially liver and kidney, are ingested.

### INTRODUCTION

THE DEVELOPMENT of a large U mining and milling industry in the Colorado Plateau during the past 30 y has led to concern about adverse health effects of these industrial activities on nearby human populations. In 1983, New Mexico had nine operating underground U mines. There were seven conventional U-recovery facilities under licensure in 1985 by the New Mexico Radiation Protection Bureau, Environmental Improvement Division (EID), although only two have operated in recent years.‡ Seven large U tailings piles in the state cover 5.5 km<sup>2</sup> (EPA 1983), and the Jackpile open pit U mine covers 10.7 km<sup>2</sup> (Momeni et al. 1983). All of these mines and mills are located in the Grants Mineral Belt, an area of about 6475 km<sup>2</sup> (Fig. 1). Since grazing land in this area of New Mexico supports about 2.7 cattle per km<sup>2</sup> (Dept. of Commerce

1984), 17,500 animals are potentially exposed to products of the U mining and milling industry.

Few studies have addressed radionuclide concentrations in domestic animals raised near U mines or mills. Yet, evidence from two previous investigations indicates that there may be radionuclide contamination of the food chain leading to humans by the U mining and milling industry. Holtzman et al. collected animals near Grants, New Mexico, in 1979 and found that muscle, lung, and kidney tissue from wild rabbits foraging near U mill tailings piles had higher mean concentrations of  $^{226}\text{Ra}$  than did control rabbits (Holtzman et al. 1979). They also showed that grass irrigated with mine dewatering effluent had elevated  $^{226}\text{Ra}$  concentrations and that femurs of cattle grazing on land irrigated by mine water had higher levels of both  $^{226}\text{Ra}$  and  $^{210}\text{Pb}$ , compared to controls.

Another study was conducted in 1979 at Church

\* Present address: Lovelace Medical Foundation, Clinical Studies Division, 2441 Ridgcrest Drive SE, Albuquerque, NM 87108.

† Present address: Jacobs Engineering Group, Radiological Services, 5301 Central Ave NE, Albuquerque, NM 87108. Author to whom reprint requests should be addressed.

‡ Information on file, Radiation Protection Bureau, Environmental Improvement Division, New Mexico Health and Environment Department, Santa Fe, NM 87504-0968.

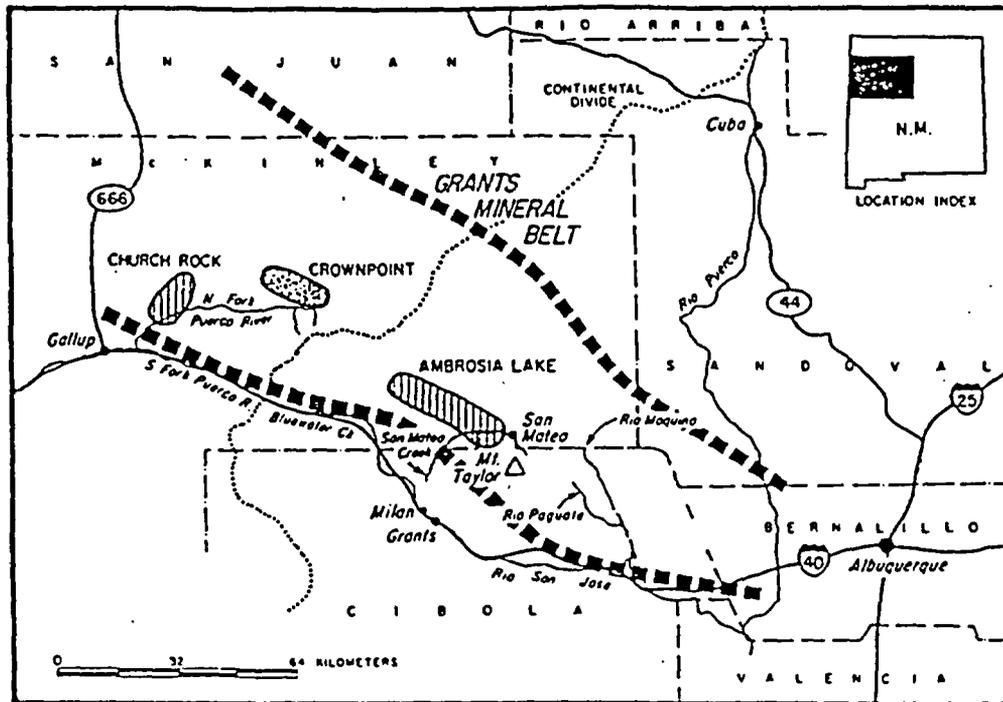


Fig. 1. Grants Mineral Belt, U mining and milling region in northwest New Mexico.

Rock, New Mexico, in response to an accidental spill of U tailings liquid into a stream of mine dewatering effluent (Ruttenber et al. 1984). Investigation into the potential human health consequences of the accident included radiochemical analyses of muscle, liver, and kidney tissue from livestock that grazed near the banks of the stream and drank mine water. Radionuclide concentrations were higher than controls, both in animals exposed to the spill and in those exposed only to U mine dewatering effluent.

We conducted the present investigation to determine whether cattle grazing in areas with U mining and milling activity have tissue radionuclide concentrations that are above background and whether regular consumption of these tissues could expose humans to excessive internal radiation doses. Current U.S. standards for the nuclear fuel cycle limit radiation doses to the public to  $250 \mu\text{Sv y}^{-1}$  to any organ except thyroid, but exempt radiation doses from U mine effluent and from Rn and its daughters (EPA 1977). Evidence of food chain contamination near mines and mills could raise questions as to the adequacy of these standards.

## METHODS

### Study site selection

Two areas in the Ambrosia Lake region, an 80-km<sup>2</sup> valley located in the Grants Mineral Belt (Fig. 1) of northwestern New Mexico, were chosen for this study because Ambrosia Lake has been the site of intensive U mining and milling since the late 1950s. Numerous tunnels un-

dermine the area, which is dotted with ventilation shafts (Fig. 2). A large U milling facility, which was opened in 1957, is licensed to process  $6.0 \times 10^6 \text{ kg d}^{-1}$  of ore. There are two U mill tailings piles in the valley. The first pile was active until 1984 and is  $0.99 \text{ km}^2$  in size, while the second tailings pile, covering  $0.42 \text{ km}^2$ , has been inactive since 1963. Continuous discharges of mine dewatering effluent, currently treated by ion exchange to remove natural U and by barium chloride to remove  $^{226}\text{Ra}$ , are available to domestic animals and provides the only water source for some. Tailings pile 1 and its associated lagoons are fenced to prevent access. However, animals do have access to liquids collecting on top of tailings pile 2.

It was estimated that about  $4.5 \text{ PBq y}^{-1}$  (122 kCi) of Rn gas was released in the 1970s from mine vents in Ambrosia Lake (Jackson et al. 1980). In addition, Rn is released from the tailings piles, from numerous mine waste piles, and from soil in the area. The total Rn released per year to the atmosphere was estimated to be about  $5.8 \text{ PBq}$  (157 kCi) (Buhl et al. 1985). Results of a 1978–1979 study conducted in Ambrosia Lake by Buhl et al. indicated that the numerical value of the state and federal Rn limit of  $0.11 \text{ Bq L}^{-1}$  above background (State of NM 1980; NRC 1986) was exceeded at four of nine air sampling stations (Buhl et al. 1985). The overall two-year average for all the stations ( $0.15 \text{ Bq L}^{-1}$ ) also exceeded the limit. However, no regulations were violated as this limit exempts contributions from any mining activities. Subsequent monitoring of Rn levels in Ambrosia Lake between 1980–1984†

*Handwritten notes:*  
 (1) This is a good example of a  
 food program - health (with  
 issues) - a very good  
 (2) 10/16/89

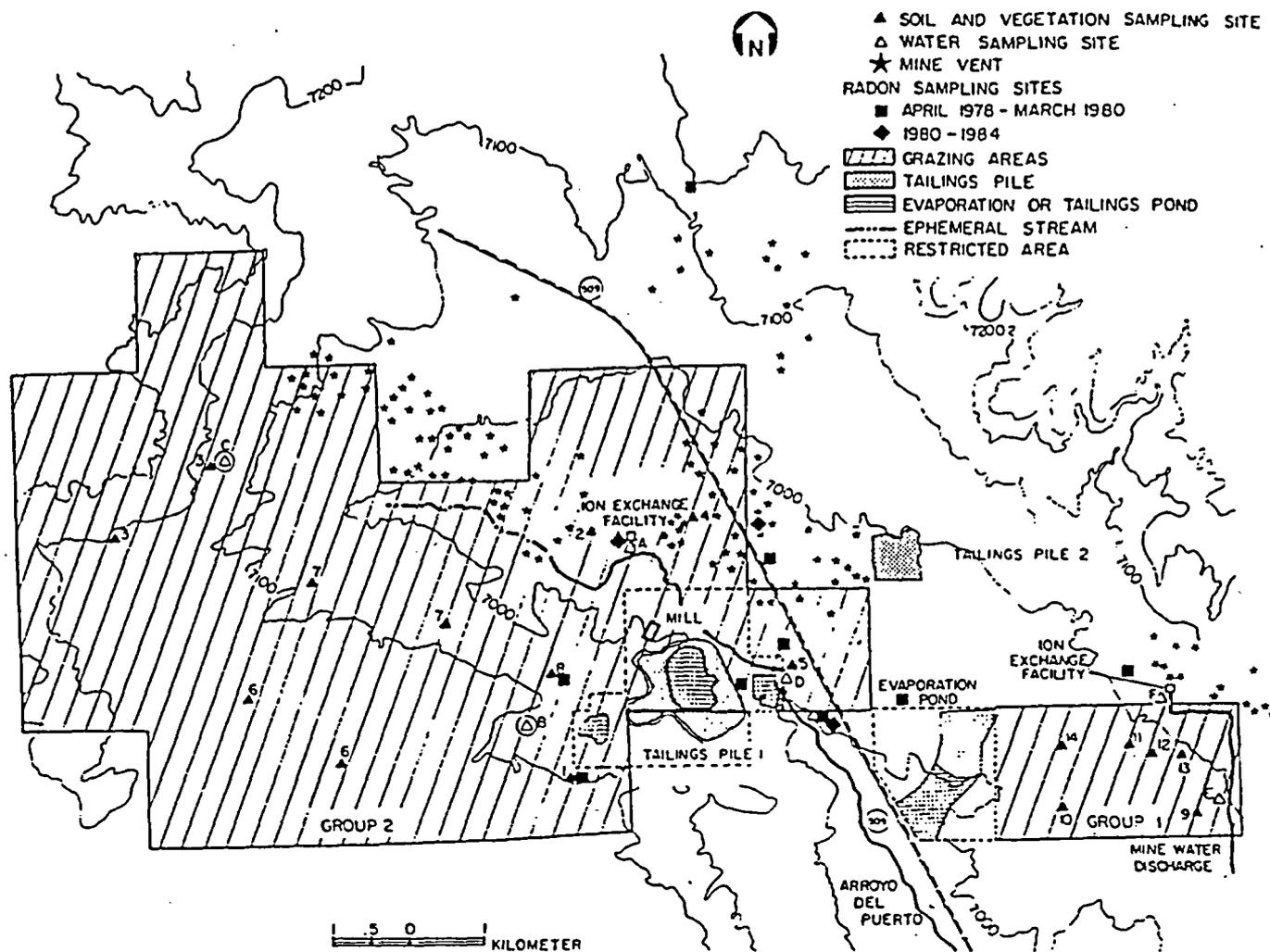


Fig. 2. Cattle grazing areas and environmental sampling sites. Ambrosia Lake. New Mexico.

revealed similarly elevated ambient air Rn concentrations (Fig. 2). Thus, cattle in the area are potentially exposed to Rn and its decay products, windblown tailings or ore, and mining effluent.

Crownpoint, the control study site, is also in the Grants Mineral Belt, approximately 40 km northwest of Ambrosia Lake. The nearest active U impoundment is an *in situ* pilot plant approximately 8 km to the northeast. An undeveloped mine shaft is located 5 km southeast of the control animals' grazing site. There are no other U industrial activities in the area. Thirty-seven Rn measurements taken at distances of 0.8–5 km from the undeveloped mine and 5–8 km from the *in situ* pilot plant have averaged  $.0056 \pm .0074 \text{ Bq L}^{-1}$  (Buhl et al. 1985). These Rn concentrations are consistent with averages from unmined areas in the Grants Mineral Belt (Buhl et al. 1985).

Natural background radioactivity was not measured in Ambrosia Lake prior to start-up of the mining and milling operations at these sites. However, the Crownpoint

area of New Mexico is rich in underground U. Therefore, it is an area with potentially high background radiation that is still relatively undisturbed. For these reasons, Crownpoint represented an appropriate baseline for comparison to animals raised near U mines or mills.

#### Cattle selection and tissue sampling

All cattle were purchased and slaughtered in October 1983. Five cattle were obtained from each of two ranchers in Ambrosia Lake. Group 1 cattle grazed in a 4.4 km<sup>2</sup> fenced area that had frequently been flooded by dewatering effluent from a nearby U mine. The treatment plant (Fig. 2) that processed this water to remove U and <sup>226</sup>Ra was built in 1976 but has not been regulated by the EID due to pending litigation. Group 1 cattle's only water source was mine dewatering effluent. Group 2 cattle grazed in a much larger open area (Fig. 2) and had access to surface impoundments as well as dewatering effluent. Ten animals were purchased in the control area near Crownpoint. Information on sex, birth date, place of birth,

health, and food and water sources was obtained for all animals at the time of purchase.

Exposed and control cattle were transported to an abattoir and sacrificed within 48 h. A United States Environmental Protection Agency (EPA) veterinarian and New Mexico EID staff obtained the specimens while taking precautions to prevent cross-contamination of tissues. Nondisposable equipment was washed thoroughly between sample collections. Specimens were individually bagged and identified. Tissues obtained from each animal for analysis included several kilograms of the upper thigh muscle, the right lobe of the liver, a whole kidney, and the entire right femur. Tissues were refrigerated and transported to the analytical laboratory for analysis. Backup and quality control specimens (Appendix A) were frozen.

#### Environmental sampling

Composite samples of grass and soil were collected from grazing areas in Ambrosia Lake (Fig. 2) and from the control area. Sampling sites in Ambrosia Lake Group 1 and in the control area were chosen by placing a grid over the area map and choosing sites at random from this grid. At the Ambrosia Lake Group 2 site, sections were chosen at random and samples collected near the center of each section. Grasses in a square meter area were clipped at soil level and analyzed unwashed. Soil samples

were collected in each vegetation quadrat to a depth of 5 cm and a volume of 600 cm<sup>3</sup>. Water samples were obtained from all water sources available to the study cattle in Ambrosia Lake and Crownpoint. Approximately 3.8 L of unfiltered water was collected at each source and treated with 20 mL of concentrated nitric acid to form a 0.5% HNO<sub>3</sub> solution. This technique minimizes plating of radionuclides on sample containers.

#### Laboratory methods

Eberline Corporation in Albuquerque, New Mexico, performed the radiochemical analyses. Each tissue was analyzed for <sup>238</sup>U, <sup>234</sup>U, <sup>230</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb, and <sup>210</sup>Po. In addition, split samples of muscle, liver, and kidney tissues from six randomly chosen cattle were analyzed for the above radionuclides by the EPA, Environmental Monitoring Systems, Las Vegas, Nevada (EPA-Las Vegas) for quality control purposes (Appendix A).

The methods for measuring radionuclide concentrations in animal tissues and environmental samples were derived from published EPA and United States Department of Energy analytical procedures (EPA 1979; DOE 1982). Tissue samples were weighed (Table 1) and dried at 105°C for approximately 24 h. About 200 g of the dried sample were ashed in a muffle furnace at 500°C, then wet ashed repeatedly with concentrated nitric acid (HNO<sub>3</sub>) and hydrogen peroxide to dissolve the sample.

Table 1. Approximate sample weights and lower limits of detection for radionuclide analyses of cattle tissue, vegetation, soil, and water, Eberline Laboratories, Albuquerque, New Mexico.

Radionuclide	Liver, Muscle		Kidney		Bone	
	Wet Wt. (g)	LLD (mBq kg <sup>-1</sup> )	Wet Wt. (g)	LLD (mBq kg <sup>-1</sup> )	Wet Wt. (g)	LLD (mBq kg <sup>-1</sup> )
<sup>238</sup> U, <sup>234</sup> U	200	7.4	40	37.0	50	29.6
<sup>230</sup> Th	200	7.4	40	37.0	50	29.6
<sup>226</sup> Ra	100	7.4	20	37.0	100	7.4
<sup>210</sup> Pb	500	37.0	200	92.5	200	92.5
<sup>210</sup> Po	500	37.0	200	92.5	200	92.5

Radionuclide	Vegetation		Soil		Water	
	Dry Wt. (g)	LLD (mBq kg <sup>-1</sup> )	Dry Wt. (g)	LLD (mBq kg <sup>-1</sup> )	Dry Wt. (g)	LLD (mBq L <sup>-1</sup> )
<sup>238</sup> U, <sup>234</sup> U	5	0.4	4	0.4	0.5	3.7
<sup>230</sup> Th	5	0.4	4	0.4	0.5	3.7
<sup>226</sup> Ra	5	0.4	1	1.9	0.5	3.7
<sup>210</sup> Pb	20	1.9	10	3.7	1	37.0
<sup>210</sup> Po	20	0.4	10	0.4	1	3.7

The final residue was dissolved in 8 N HNO<sub>3</sub> and diluted to a measured volume. Aliquots of this solution were used for <sup>238</sup>U, <sup>234</sup>U, <sup>226</sup>Ra, and <sup>230</sup>Th analyses. Uranium and Th were then measured by  $\alpha$  spectroscopy, and <sup>226</sup>Ra was measured by Rn de-emanation.

For the <sup>210</sup>Pb and <sup>210</sup>Po analyses, approximately 200 g of the dried sample was digested (wet ashed) repeatedly with concentrated nitric acid, hydrochloric acid (HCl) and hydrogen peroxide at 85°C until the entire sample was completely oxidized and dissolved. The sample was then dissolved in 1 N HCl to a measured volume. Aliquots of this solution were analyzed for <sup>210</sup>Po by electrodeposition and  $\alpha$  counting, and for <sup>210</sup>Pb by <sup>210</sup>Bi separation and  $\beta$  counting. Appropriate internal tracers and stable carriers were added to determine the chemical and radiochemical recovery fractions. The lower limits of detection (LLD) are presented in Table 1.

Bone samples were weighed and then cut into twelve approximately equal sections of about 3 cm in thickness. Alternate sections were combined. One combined sample was used for the determination of <sup>238</sup>U, <sup>234</sup>U, <sup>226</sup>Ra, and <sup>230</sup>Th. The remainder was analyzed for <sup>210</sup>Po and <sup>210</sup>Pb, according to the above methods.

All environmental samples (vegetation, soil, and water) were analyzed for <sup>238</sup>U, <sup>234</sup>U, <sup>230</sup>Th, <sup>226</sup>Ra, <sup>210</sup>Pb, and <sup>210</sup>Po using the same methods for measuring radionuclide concentrations as were used for tissue specimens. Tissue and bone concentrations of <sup>210</sup>Po were corrected for radioactive decay and the ingrowth of <sup>210</sup>Po from <sup>210</sup>Pb using a standard formula (Holtzman 1963). If the corrected <sup>210</sup>Po concentration was a negative number, it was assigned a value of zero.

Methods used at the EPA-Las Vegas laboratory for detecting radionuclides in animal tissues have been previously described (Ruttenber et al. 1984), with the exception that <sup>230</sup>Th recoveries were determined using a <sup>229</sup>Th tracer, followed by  $\alpha$  spectrometry. The major difference between procedures followed by the two laboratories involved the analysis of <sup>210</sup>Pb. Technicians at Eberline counted the <sup>210</sup>Bi decay product of <sup>210</sup>Pb using  $\beta$  detection equipment, while those at the EPA-Las Vegas laboratory counted the <sup>210</sup>Po formed from <sup>210</sup>Pb decay using  $\alpha$  spectrometry. In both laboratories, an error factor was calculated and reported as two standard deviations of the counting rate (EPA 1980). Negative radionuclide concentrations were reported on occasion and resulted from subtraction of background counts from sample counts. Each laboratory also used its own protocol for assuring quality control.

#### Statistical methods

Statistical analysis was performed on the computerized data set using the Statistical Analysis System (Statistical Analysis System 1985). Radionuclide concentrations in cattle tissue and bone, and concentrations in the environmental samples from each of the two Ambrosia Lake groups and Crownpoint, were compared using both parametric (multiple analysis of variance [MANOVA])

with General Linear Models [G.L.M.] for unequal sample sizes and Duncan's multiple range test) and nonparametric (Kruskal-Wallis and Wilcoxon's two-sample) statistical tests. In the MANOVA approach radionuclide concentrations were the dependent variables. Location (Ambrosia Lake Group 1, Group 2, Crownpoint) was the independent variable. Analyses of cattle tissue were performed with and without age added to the model.

Since the sample size in each group was small, it was not possible to determine whether the data were normally distributed. Therefore, nonparametric statistical tests were performed. The Kruskal-Wallis test was used to determine whether any of the three exposure groups or the control group differed significantly ( $p < 0.05$ ). If significant differences were found, Wilcoxon's rank-sum test, with continuity correction of 0.5, was used to compare each exposure group to the Crownpoint control group.

A discussion of the quality-control comparisons is given in Appendix A. Results of split sample testing were compared using a two-tailed paired-sample t-test (Zar 1974).

#### Methods for estimation of doses from cattle tissue ingestion and cancer risk estimates

An additional objective of this investigation was to determine the risk to public health from eating exposed cattle over a long period of time. Owners of the purchased animals stated that they raise, slaughter, and consume their own animals. Further, it was assumed that some individuals buy a cow or a side of beef, freeze it, and consume it over several months. Thus, some New Mexican families might purchase an exposed animal and eat large quantities of meat containing elevated radionuclide concentrations. To examine the importance of the elevated tissue radioactivity found in this study, we calculated estimates of internal radiation dose from ingesting exposed and control tissues.

The internal dose commitment received when a person ingests cattle tissue for 1 y with known radionuclide concentrations was estimated for all three groups using dose conversion factors of Dunning (Dunning 1985). Mean tissue concentrations for each exposed group and the control group were used for the calculations, and dose commitments were estimated for a 50-y period following 1 y of ingestion. F<sub>1</sub> uptake factors for absorption of specific radionuclides across the human gut were 0.05 for <sup>238</sup>U and <sup>234</sup>U, 0.0002 for <sup>230</sup>Th, 0.2 for <sup>226</sup>Ra, 0.2 for <sup>210</sup>Pb, and 0.1 for <sup>210</sup>Po (ICRP 1978). A quality factor of 20 for  $\alpha$  radiation was assumed for all dose conversion factors, in accordance with recommendations of the International Commission on Radiological Protection (ICRP 1977). We estimated doses to human kidney, liver, endosteum, and red marrow.

To estimate cancer risks from ingestion of cattle tissue, total activity of each radionuclide ingested per year was calculated and converted to  $\mu\text{Sv y}^{-1}$  using the effective dose equivalents of Dunning (Dunning 1985). The total effective dose equivalent for each scenario was then mul-

multiplied by the ICRP risk coefficient of  $100 \times 10^{-4}$  per Sv to estimate the expected number of cancer deaths (ICRP 1977). Lifetime cancer risks were expressed as the number of excess cancer deaths per million population attributable to the radiation dose received from one and 20 y of ingestion.

Internal radiation doses and cancer risks were calculated according to three scenarios of tissue consumption. Scenario 1 assumed that a family living in the described areas would slaughter and ingest all the edible parts of an animal, including its liver and kidneys, over a one-year period. This scenario assumed a total beef consumption of  $78 \text{ kg y}^{-1}$  per individual, the average per capita yearly meat consumption in the United States (ICRP 1971) and a dietary proportion of muscle, liver, and kidney comparable to that organ's percentage of the combined average weight of beef muscle, liver, and kidney, 74 kg (94.8%), 2.7 kg (3.4%), and 1.3 kg (1.87%), respectively (Ruttenber et al. 1984).

Scenario 2 assumed that a person ingested  $78 \text{ kg y}^{-1}$  of muscle from each area but did not eat liver or kidney. Scenario 3, a worst case estimate, assumed that a person ate higher percentages of liver and kidney. These percentages were the 99th percentile of reported consumption from a 1984 dietary survey of 767 adult Hispanic and non-Hispanic white New Mexicans selected randomly for a study (Samet et al. 1985). Worst case estimates assumed a liver consumption of  $13.1 \text{ kg y}^{-1}$  and a kidney consumption of  $2.6 \text{ kg y}^{-1}$ , with muscle constituting the remainder of the  $78 \text{ kg y}^{-1}$  meat intake.

## RESULTS

### Cattle data

All of the cattle were female. The average age of Ambrosia Lake Group 1 cattle was 5.0 y (range 4–6 y). Ambrosia Lake Group 2 cattle were two- and three-year-olds, with a mean age of 2.4 y. The mean age of the Crownpoint controls was 4.8 y (range 3–7 y). Except for one animal purchased as a calf from another owner, all animals were born and raised in the described areas. The owner of Ambrosia Lake Group 1 cattle stated that some of the animals in his herd were not gaining weight properly and reproduced poorly. The other owners reported their animals to be in good health. Animals from all three groups received supplemental fodder during winter. All 10 animals in the two exposed groups, and none of the 10 animals in the control group, had access to U mine dewatering effluent.

### Radionuclide concentrations in cattle

Mean radionuclide concentrations in muscle tissue of cattle from Ambrosia Lake Groups 1 and 2 were similar to those of corresponding controls, with the exception that muscle from Group 1 cattle contained significantly higher concentrations of  $^{226}\text{Ra}$  and  $^{210}\text{Po}$  than controls (Table 2). Liver and kidney from Group 1 cattle had mean radionuclide concentrations as high as and, in many cases, significantly higher than those of corresponding controls. Mean radionuclide concentrations in liver and kidney samples from Group 2 cattle generally were not as high

Table 2. Mean radionuclide concentrations in edible tissue and femurs from exposed and control cattle, Ambrosia Lake and Crownpoint, New Mexico.

Exposure Group	Radionuclide concentration ( $\text{Bq kg}^{-1}$ wet wt. $\pm$ standard error of the mean)					
	$^{238}\text{U}$	$^{235}\text{U}$	$^{232}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Pb}$	$^{210}\text{Po}$
<b>Ambrosia Lake Group 1 (n = 5)</b>						
Muscle	$0.030 \pm 0.007$	$0.03 \pm 0.01$	$0.026 \pm 0.007$	$0.15 \pm 0.05^{\text{ac}}$	$0.08 \pm 0.04$	$3.4 \pm 0.6^{\text{ac}}$
Liver	$0.19 \pm 0.02^{\text{ac}}$	$0.20 \pm 0.02^{\text{ac}}$	$0.17 \pm 0.08^{\text{b}}$	$0.46 \pm 0.17^{\text{ac}}$	$3.4 \pm 3.2$	$56 \pm 17^{\text{ac}}$
Kidney	$0.41 \pm 0.07^{\text{ac}}$	$0.41 \pm 0.08^{\text{ac}}$	$0.60 \pm 0.21^{\text{ab}}$	$4.3 \pm 1.6^{\text{ac}}$	$2.9 \pm 0.9$	$65 \pm 19^{\text{ab}}$
Femur	$3.2 \pm 0.9^{\text{b}}$	$3.5 \pm 1.1^{\text{b}}$	$0.37 \pm 0.20^{\text{a}}$	$263 \pm 78^{\text{ac}}$	$42 \pm 9$	$53 \pm 50$
<b>Ambrosia Lake Group 2 (n = 5)</b>						
Muscle	$0.019 \pm 0.007$	$0.030 \pm 0.007$	$0.010 \pm 0.001$	$0.007 \pm 0.015$	$0.05 \pm 0.03$	$0.31 \pm 0.13$
Liver	$0.07 \pm 0.03^{\text{b}}$	$0.06 \pm 0.03^{\text{b}}$	$0.041 \pm 0.007$	$0.01 \pm 0.01$	$0.38 \pm 0.27$	$12 \pm 5$
Kidney	$0.25 \pm 0.09^{\text{ac}}$	$0.27 \pm 0.10^{\text{ab}}$	$0.19 \pm 0.04^{\text{b}}$	$0.85 \pm 0.33^{\text{b}}$	$13 \pm 5^{\text{a}}$	$31 \pm 7$
Femur	$6.1 \pm 2.9^{\text{ab}}$	$6.5 \pm 2.6^{\text{ac}}$	$0.20 \pm 0.13$	$143 \pm 40^{\text{ac}}$	$35 \pm 13$	$87 \pm 68$
<b>Crownpoint Control (n = 10)</b>						
Muscle	$0.026 \pm 0.007$	$0.030 \pm 0.004$	$0.015 \pm 0.004$	$0.011 \pm 0.007$	$0.09 \pm 0.06$	$0.52 \pm 0.13$
Liver	$0.015 \pm 0.004$	$0.015 \pm 0.004$	$0.06 \pm 0.05$	$0.011 \pm 0.007$	$0.25 \pm 0.14$	$9 \pm 2$
Kidney	$0.05 \pm 0.01$	$0.06 \pm 0.02$	$0.09 \pm 0.03$	$0.17 \pm 0.07$	$3.0 \pm 0.6$	$17 \pm 5$
Femur	$0.24 \pm 0.15$	$0.26 \pm 0.10$	$0.09 \pm 0.04$	$5.6 \pm 1.9$	$15 \pm 3$	$11 \pm 7$

<sup>a</sup> Significantly ( $p < 0.05$ ) higher than Crownpoint control, analysis of variance Duncan's multiple range test

<sup>b</sup> Significantly ( $p < 0.05$ ) higher than Crownpoint control, Wilcoxon's two-sample test

<sup>c</sup> Significantly ( $p < 0.003$ ) higher than Crownpoint control, Wilcoxon's two-sample test

as those from Group 1. However, in all but two instances, mean tissue radionuclide concentrations in Group 2 cattle were higher than those of respective controls. Radionuclide concentrations in the femurs of animals from both Ambrosia Lake groups also were higher than those of controls. When age was added to location as an independent variable in the MANOVA model, the effect of location on mean radionuclide concentrations remained statistically significant.

#### Radionuclide concentrations in environmental samples

Results of vegetation analysis indicated that levels of  $^{230}\text{Th}$  and  $^{226}\text{Ra}$  were significantly higher than control concentrations in both of the grazing areas sampled in Ambrosia Lake (Table 3).

Radionuclide levels in soil sampled from Ambrosia Lake Group 1 were significantly elevated over those of controls (Table 3). Mean radionuclide concentrations in soil from Ambrosia Lake Group 2 were several times higher than those of controls for all radionuclides except  $^{210}\text{Po}$ , but the differences did not attain statistical significance. Soil from sampling sites 11-13 in Group 1 and sites 2, 4, and 5 in Group 2 had much higher radionuclide levels than did soil collected at the other sites in the respective grazing areas (Table 4).

Water samples collected from Ambrosia Lake Group 1 had higher mean concentrations of  $^{238}\text{U}$  and  $^{234}\text{U}$  than controls. Ambrosia Lake Group 2 water contained higher levels of these radionuclides than controls, but the differences were not significant statistically.

## DISCUSSION

### Summary and interpretation of study results

The principal objective of the present study was to determine whether radionuclide concentrations in the tissues of cattle raised near U mines and mills were higher

than those of unexposed animals. Results indicated that both groups of cattle exposed to U mine and mill discharges and wastes had elevated tissue radionuclides, compared with controls.

This study had several limitations. First, only a small number of cattle were tested from each area. Since there was substantial variability between radionuclide concentrations measured in animals from each group, the standard errors were large. Second, there was variability in the results of split sample testing, especially the  $^{210}\text{Po}$  measurements (Appendix A). It is possible that the  $^{210}\text{Po}$  concentrations reported may be twice as high as the true values. A third problem was that the radionuclide concentrations measured in the environmental samples may not have been representative of those to which the cattle were actually exposed. Since the cattle were living in their respective areas for two to seven years, many samples of soil, vegetation, and water tested periodically would have been required to characterize radionuclide levels in the cattle's environments.

Untreated U mine water may contain significant levels of  $^{238}\text{U}$ -chain radionuclides. Gallaher and Goad, in a study of U mine water in New Mexico, reported a median of  $6.3 \text{ Bq L}^{-1}$   $^{226}\text{Ra}$  and  $5.4 \text{ mg L}^{-1}$  U (equivalent to about  $70 \text{ Bq L}^{-1}$  each of  $^{238}\text{U}$  and  $^{234}\text{U}$ ) (Gallaher and Goad 1981). Thus, if ion exchange plants were not operating effectively, study cattle could have ingested water containing much higher radionuclide levels than those given in the present report. Finally, since cattle selected for the study were not a random sample, the results of this study should not be considered to completely describe the tissue levels of all animals grazing in Ambrosia Lake.

Despite the limitations of this investigation, the findings support the conclusion that the elevated radionuclide levels found in cattle tissue from Ambrosia Lake resulted from the cattle's exposures to radionuclide byproducts of the U mining and milling industry. This conclusion is

Table 3. Mean radionuclide concentrations in vegetation, soil, and water, Ambrosia Lake and Crownpoint, New Mexico.

Exposure Group	Types of Sample (n)	Radionuclide concentration ( $\text{Bq g}^{-1}$ dry wt.; water, $\text{Bq L}^{-1}$ = standard error of the mean)					
		$^{238}\text{U}$	$^{234}\text{U}$	$^{230}\text{Th}$	$^{226}\text{Ra}$	$^{210}\text{Po}$	$^{210}\text{Pb}$
Ambrosia Lake Group 1	Vegetation (5)	$0.06 \pm 0.04$	$0.06 \pm 0.04$	$0.03 \pm 0.01^{\text{a}}$	$0.13 \pm 0.06^{\text{c}}$	$0.02 \pm 0.004$	$0.13 \pm 0.05$
	Soil (6)	$1.1 \pm 0.7^{\text{b}}$	$1.3 \pm 0.8^{\text{b}}$	$4.3 \pm 2.3^{\text{a,b}}$	$19 \pm 12^{\text{a}}$	$22 \pm 16^{\text{c}}$	$15 \pm 24^{\text{b}}$
	Water (2)	$25 \pm 1^{\text{a}}$	$28 \pm 0.4^{\text{a}}$	$0.01 \pm 0.002$	$0.07 \pm 0$	$0.25 \pm 0.11$	$0.59 \pm 0.44$
Ambrosia Lake Group 2	Vegetation (8)	$0.04 \pm 0.02$	$0.04 \pm 0.02$	$0.13 \pm 0.07^{\text{a}}$	$0.06 \pm 0.03^{\text{c}}$	$0.19 \pm 0.09$	$0.11 \pm 0.05$
	Soil (8)	$0.15 \pm 0.07$	$0.18 \pm 0.09$	$0.56 \pm 0.33$	$0.31 \pm 0.16$	$0.46 \pm 0.22$	$0.07 \pm 0.03$
	Water (4)	$2.9 \pm 2.7$	$2.9 \pm 2.6$	$0.04 \pm 0.03$	$0.05 \pm 0.03$	$0.24 \pm 0.06$	$0.53 \pm 0.41$
Crownpoint Control	Vegetation (4)	$0.007 \pm 0.002$	$0.007 \pm 0.002$	$0.002 \pm 0.001$	$0.003 \pm 0.001$	$0.04 \pm 0.004$	$0.01 \pm 0.01$
	Soil (4)	$0.03 \pm 0.003$	$0.026 \pm 0.004$	$0.033 \pm 0.007$	$0.03 \pm 0.004$	$0.09 \pm 0.02$	$0.07 \pm 0.01$
	Water (2)	$0.03 \pm 0.02$	$0.04 \pm 0.02$	$0.007 \pm 0.004$	$0.09 \pm 0.03$	$0.19 \pm 0$	$0.07 \pm 0.07$

<sup>a</sup> Significantly ( $p < .05$ ) higher than Crownpoint control, analysis of variance, Duncan's multiple range test

<sup>b</sup> Significantly ( $p < .05$ ) higher than Crownpoint control, Wilcoxon's two-sample test

Table 4. Radionuclide concentrations in soil and water samples, Ambrosia Lake, New Mexico.

Exposure Group	Type of Sample	Site No.	Radionuclide Concentration (soil, Bq g <sup>-1</sup> dry weight; water, Bq L <sup>-1</sup> )						
			<sup>238</sup> U	<sup>235</sup> U	<sup>232</sup> Th	<sup>226</sup> Ra	<sup>210</sup> Pb	<sup>210</sup> Po	
Ambrosia Lake Group 1	Soil	9	0.07	0.07	0.07	0.03	0.2	0.2	
		10	0.3	0.3	0.1	0.5	0.3	0.2	
		11	0.8	1.0	3.7	6.3	4	6.3	
		12	0.8	1.0	7.0	41	26	42	
		13	4.8	5.2	14	67	100	39	
		14	0.04	0.03	0.2	0.04	0.2	0.1	
	Water	E	26	29	0.01	0.07	0.1	1.1	
		F	24	28	0.004	0.07	0.4	0.2	
	Ambrosia Lake Group 2	Soil	1	0.02	0.02	0.03	0.04	0.1	0.09
			2	0.6	0.7	2.2	1.2	1.5	0.2
3			0.1	0.1	0.07	0.07	0.07	0.04	
4			0.3	0.3	0.2	0.3	0.4	0	
5			0.1	0.1	1.7	0.8	1.6	0	
6			0.02	0.02	0.03	0.03	0.06	0.01	
7			0.02	0.02	0.03	0.04	0.1	0	
8			0.04	0.04	0.04	0.05	0.1	0.1	
Water		A	11	11	0.01	0	0.3	0	
		B	0.5	0.6	0.01	0.02	0.1	0	
		C	0.03	0.04	0.05	0.05	0.4	0.9	
		D	0.004	0.01	0.1	0.1	0.1	1.6	

supported by the consistency of the data and the magnitude of the differences in radionuclide concentrations between exposed versus unexposed cattle.

The environmental data collected in this investigation, although limited, also strongly support the conclusion that the elevated radionuclide levels in cattle tissue resulted from exposures to U mining and milling. Ambrosia Lake Group 1, the exposure area most impacted by the U mining and milling industry, had the highest concentrations of environmental radionuclides and is the area in which cattle tissues contained the highest radionuclide levels. Correspondingly, the Ambrosia Lake Group 2 cattle tissue and environmental samples had intermediate levels of radioactivity, and the control samples had the lowest levels.

Evidence indicates that the high radionuclide levels found in environmental samples were not due to natural sources of radiation. Natural background radioactivity was not measured in Ambrosia Lake prior to start-up of the mining and milling operations. However, soil samples collected at a depth of 30 cm in Ambrosia Lake in another study were similar to those collected at the surface in Crownpoint (Buhl et al. 1985). Thus, the extremely high levels of <sup>226</sup>Ra in surface soil probably reflected contributions from the U mining and milling industry.

In the present study, the grazing area for Ambrosia Lake Group 1 cattle has been flooded by mining effluent for years. Prior to 1979, when the ion exchange plant was built, the water that flooded this area was untreated U mine dewatering effluent. Soil from sample sites 11-13 contained elevated levels of radionuclides, compared to

the remaining samples (Table 4). These sites were close to the discharge from the ion exchange plant but farther from the Tailings Pile 2 or other tailings piles than sample sites 10 and 14, which had much lower levels of soil radionuclides (Fig. 2). In this case, it appears that mine water rather than windblown tailings contributed more to high levels of <sup>238</sup>U-chain radionuclides in grazing area 1.

The grazing area for Ambrosia Lake Group 2 cattle was not irrigated by U mine dewatering effluent. Soil containing the highest levels of <sup>238</sup>U-chain radionuclides was from sampling sites 2, 4, and 5. These sites were very close to Tailings Pile 1, and mine vents were abundant in these areas. Radium-226 in soil from these sampling sites averaged 750 mBq g<sup>-1</sup>. Soil from sites 3, 6, and 7, which are farthest from the mill and its tailings pile, had levels of <sup>226</sup>Ra that averaged 48 mBq g<sup>-1</sup>. The elevated radionuclides in soil from grazing area 2 have therefore probably resulted from windblown tailings or Rn daughters. These differences could not easily be attributed to variations in natural radioactivity.

The conclusion of this investigation is also supported by previous research into cattle contamination by the U mining and milling industry. Holtzman et al. measured tissue concentrations of <sup>226</sup>Ra, <sup>210</sup>Pb and <sup>210</sup>Po in two cows that foraged near the Anaconda U mill tailings pile in New Mexico and found higher tissue radioactivity in the femurs of these animals compared to controls (Holtzman et al. 1979).

Another recent study examined ten sheep and seven cattle raised in Church Rock, New Mexico, where animals regularly drank U mine dewatering effluent. The findings

Table 5. Dose to human target organs from ingestion of cattle tissue, scenario 1, Ambrosia Lake and Crownpoint, New Mexico.

Exposure Group	Nuclide	Target Organs (50 y dose commitments in $\mu\text{Sv y}^{-1}$ of ingestion)			
		Kidney	Liver	Endosteum	Red Marrow
Ambrosia Lake Group 1	$^{235}\text{U}$	1.31	0.0071	3.05	0.20
	$^{238}\text{U}$	1.52	0.0076	3.55	0.23
	$^{232}\text{Th}$	0.0021	0.019	11.2	0.86
	$^{226}\text{Ra}$	1.60	1.60	121.2	10.7
	$^{210}\text{Pb}$	50.6	116.5	405.1	27.9
	$^{210}\text{Po}$	1238.0	210.7	39.5	39.5
	Total	1290.0	330.0	580.0	79.0
Ambrosia Lake Group 2	$^{235}\text{U}$	0.81	0.0046	1.96	0.13
	$^{238}\text{U}$	1.29	0.0070	3.11	0.19
	$^{232}\text{Th}$	0.0008	0.0063	3.70	0.29
	$^{226}\text{Ra}$	0.15	0.16	12.0	1.06
	$^{210}\text{Pb}$	64.1	147.4	512.9	35.3
	$^{210}\text{Po}$	246.8	42.0	7.84	7.88
	Total	310.0	190.0	540.0	45.0
Crownpoint Control	$^{235}\text{U}$	0.79	0.0044	1.88	0.13
	$^{238}\text{U}$	1.04	0.0057	2.49	0.16
	$^{232}\text{Th}$	0.0010	0.0087	5.10	0.39
	$^{226}\text{Ra}$	0.09	0.092	6.61	0.59
	$^{210}\text{Pb}$	30.6	70.3	244.5	16.8
	$^{210}\text{Po}$	216.1	36.8	6.90	6.90
	Total	250.0	110.0	270.0	25.0

<sup>a</sup>Scenario 1 assumes an annual ingestion of 74 kg muscle, 2.7 kg liver, and 1.3 kg kidney.

of this investigation are presented elsewhere<sup>§</sup> but are similar to those of Rutenber and his colleagues (Rutenber et al. 1984) and support the conclusion that radionuclide levels in animals from Church Rock were higher than controls.

#### Radiation doses and cancer risk estimates from cattle ingestion

In scenario 1, the annual ingestion of muscle, liver, and kidney from control animals incurred a 50-y dose commitment of 250  $\mu\text{Sv}$  to the kidney and 270  $\mu\text{Sv}$  to endosteum (Table 5). Consumption of Ambrosia Lake Group 2 cattle resulted in radiation doses 1.2–2 times greater than those incurred from eating control cattle tissue. The dose incurred from eating Group 1 cattle for 1 y was associated with an even higher dose, especially to kidney (1000  $\mu\text{Sv}$  above the control). Polonium-210 and  $^{210}\text{Pb}$  were the most important nuclides in terms of dose to human kidney, liver, and red marrow. Lead-210, followed by  $^{226}\text{Ra}$ ,  $^{210}\text{Po}$ , and  $^{230}\text{Th}$ , contributed substantial fractions of the dose to endosteum. Because it was possible that the reported  $^{210}\text{Po}$  measurements were higher than

the true values, the dose contributions from  $^{210}\text{Po}$  may be overestimated by a factor of about two.

Cancer mortality risks associated with these doses for scenario 1 were one chance in 1,640,000 from ingesting control beef, one chance in 1,180,000 from eating Ambrosia Lake Group 2 cattle, and one chance in 350,000 from eating Ambrosia Lake Group 1 cattle. Continuous ingestion of Group 1 cattle for 20 y would incur a lifetime cancer mortality risk of one chance in 18,000. However, this estimate did not take into account competing sources of risk which would effectively lower this risk estimate.

Eliminating liver and kidney from the diet and eating muscle tissue alone (scenario 2) reduced the internal radiation dose (Table 6). The dose to kidney from ingesting Ambrosia Lake Group 1 cattle, for example, was reduced by about 55%. The ingestion of Ambrosia Lake Group 2 cattle was associated with a negligible excess cancer mortality risk. Consumption of beef from Ambrosia Lake Group 1 resulted in a risk of one chance in 670,000.

The worst case estimates of scenario 3 predicted much higher doses (Table 6). For instance, the resulting 50-y dose commitment to kidney from 1 y of ingestion was enhanced by a factor of 2.3, to 3000  $\mu\text{Sv}$ . For 1 y of ingestion, corresponding cancer mortality risk estimates were one chance in 150,000 for the highest exposure group (Ambrosia Lake Group 1) and one chance in 500,000 for Ambrosia Lake Group 2.

<sup>§</sup> Millard, J. B.; Lapham, S. C. Radionuclide concentrations in sheep and cattle grazing near a U mining and milling facility in Church Rock, New Mexico (unpublished report). Jacobs Engineering, Albuquerque, NM 87108.

Table 6. Dose to human target organs from ingestion of cattle tissue, scenarios 2 and 3, Ambrosia Lake and Crownpoint, New Mexico.

Scenario	Location	Target Organs (50 y dose commitments in $\mu\text{Sv y}^{-1}$ of ingestion)			
		Kidney	Liver	Endosteum	Red Marrow
Scenario 2	Ambrosia Lake Group 1	693	155	245	39
	Ambrosia Lake Group 2	79	48	144	12
	Crownpoint Control	124	61	169	15
Scenario 3	Ambrosia Lake Group 1	3000	840	1530	190
	Ambrosia Lake Group 2	786	381	982	88
	Crownpoint Control	547	189	397	42

<sup>a</sup>This scenario assumes an annual ingestion of 78 kg of muscle (no liver or kidney).

<sup>b</sup>This scenario assumes an annual ingestion of 62.3 kg muscle, 13.1 kg liver, 2.6 kg kidney.

Dose commitments were calculated according to estimates given by Dunning. Other dose conversion factors, which include higher and lower values than those of Dunning, are reported in the literature (McDowell-Boyer et al. 1979). Fifty-year dose commitments calculated in this report may have underestimated the dose to potentially exposed children or infants since higher dose conversion factors are recommended for young age groups (NRC 1980). However, 50-y dose commitments overestimated doses to older persons since their expected lifespan is less than 50 y.

For all the assumed scenarios, cancer mortality risks attributable to eating beef from each of the exposure groups were within the ICRP's range of acceptability (one chance in 100,000 to one chance in 1,000,000) for fatal risks to the general public (ICRP 1977). Calculations presented in this report were based on the assumption that a person eats 78 kg of area beef in 1 y. It is probable that the general public is not exposed to this extent. However, for local residents who have eaten area meat, especially liver and kidney, for a prolonged period of time, cancer mortality risk estimates may exceed this acceptable limit.

EPA standards and New Mexico EID regulations limit the organ doses contributed by the nuclear fuel cycle to individuals to  $250 \mu\text{Sv y}^{-1}$ , but currently exempt radiation exposures from U mine effluents, and from Rn and its daughters, which include  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  (EPA 1977; State of NM 1980). Thus, although the dose incurred from the hypothetical ingestion of Ambrosia Lake Group 1 cattle for 1 y would exceed  $250 \mu\text{Sv y}^{-1}$ , no existing standards or regulations would be violated.

The present investigation was not designed to determine whether the source of radioactivity was mill tailings, mine dewatering effluent, or the inhalation and/or ingestion of Rn and its daughters. The most highly contaminated animals were exposed to all of these sources. Further environmental sampling and measurements of tissue radionuclide concentrations in animals exposed only to dewatering effluents, or to mill tailings, would be needed to identify the relative contribution from each source. Until these studies are completed, restricting access of livestock to U mine dewatering effluent and to land that has been irrigated with mine water—or is in proximity to mill tailings—would markedly reduce the probability of food chain contamination.

*Acknowledgments*—We wish to acknowledge the New Mexico legislature for providing public funds necessary to conduct this study.

The authors thank Paul Hahn, Wayne Bliss, and all of the United States Environmental Protection Agency staff who assisted the authors in collecting specimens and performing laboratory quality control analyses. We also thank staff of the Indian Health Service, especially Wayne Moeller, Don Payne, and Don Bitsilly; Dr. Chandrasekaran and Kathy Burnham of Eberline Laboratory; and Dave Baggett and Kent Breese of the Environmental Improvement Division for their assistance in this project.

We thank Richard Holtzman of the U.S. Nuclear Regulatory Commission; Jim Rutenber, Centers for Disease Control; Charles Dowell, Charles Reaux, and Wayne Moeller, Indian Health Service; Jim McInroy, Los Alamos National Laboratories; Hank May, Paul Hahn, Wayne Bliss, and Mike Mardis of the Environmental Protection Agency; and Stuart Castle and Ken Hargis, New Mexico Health and Environment Department, for their review of this manuscript.

## REFERENCES

- Buhl, T.; Millard, J.; Baggett, D. Rn and Rn decay product concentrations in New Mexico's U mining and milling district. Santa Fe, NM: Radiation Protection Bureau, Environmental Improvement Div.; 1985.
- Dunning, D. E. Estimates of internal dose equivalent from inhalation and ingestion of selected radionuclides. Springfield, VA: National Technical Information Service; WIPP-DOE-176 (Rev. 1); 1985.
- Environmental Protection Agency. Environmental radiation protection standards for nuclear power operations. Title 40, Part 190. Washington, DC: U.S. Government Printing Office; Fed. Register 42:2858-2861; 1977.
- Environmental Protection Agency. Radiochemical analysis procedures for analysis of environmental samples. Springfield, VA: National Technical Information Service; EMSL-LV-0539-17; 1979.
- Environmental Protection Agency. Prescribed procedures for measurement of radioactivity in drinking water. Springfield, VA: National Technical Information Service; EPA-600/4-80-032; 1980.
- Environmental Protection Agency. EPA's proposed standards for controlling, stabilizing mill tailings at U Th processing sites. 40 CFR, Part 192, 1983:29-48. Title 40 of the Code of Federal Regulations—Protection of the Environment, Parts 190-399. Washington, DC: U.S. Government Printing Office; 869-001-00135-61, 1987 ed.
- Gallagher, B. M.; Goad M. S. Water quality aspects of U mining and milling in New Mexico. Santa Fe, NM: New Mexico Geological Society. Special Publ. No. 10:85-91; 1981.
- Holtzman, R. B. Measurement of the natural contents of RaD ( $^{210}\text{Pb}$ ) and RaF ( $^{210}\text{Po}$ ) in human bone—estimates of whole body burdens. *Health Phys.* 9:385-400; 1963.
- Holtzman, R. B.; Urnezis, P. W.; Padova, A.; Bobula, C. M., III. Contamination of the human food chain by U mill tailings piles. Springfield, VA: National Technical Information Service; NUREG/CR-0758/ANL/ES-69; 1979.
- International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. I.O.A.; Oxford: Pergamon Press; 1971.
- International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. Problems involved in developing an index of harm. Elmsford, NY: Pergamon Press; 1977.
- International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. ICRP Publ. No. 30, Part I; Oxford: Pergamon Press; 1978.
- Jackson, P. O.; Glissmeyer, J. A.; Enderlin, W. I.; Schwendiman, L. C.; Wagman, N. A.; Perkins, R. W. An investigation of Ra-222 emissions from underground uranium mines. Richland, WA: Batelle Pacific Northwest Laboratory. PNL-3262, NUREG/CR-1273; 1980.
- McDowell-Boyer, L. M.; Watson, A. P.; Travis, C. C. Review and recommendations of dose conversion factors and environmental transport parameters for  $^{210}\text{Pb}$  and  $^{226}\text{Ra}$ . Oak Ridge National Laboratory. Springfield, VA: National Technical Information Service; NUREG/CR-0574; 1979.
- Momeni, M. H.; Tsai, S. Y. H.; Yang, J. Y.; Gureghian, A. B.; Dungey, C. E. Radiological impacts of Jackpile-Paguete uranium mines. Argonne National Laboratory. Springfield, VA: National Technical Information Service; ANL/ES-131; 1983.
- Ruttenber, A. J.; Kreiss, K.; Douglas, R. L.; Buhl, T. E.; Millard, J. The assessment of human exposure to radionuclides from a U mill tailings release and mine dewatering effluent. *Health Phys.* 47:21-35; 1984.
- Samet, J. M.; Skipper, B. J.; Humble, C. G.; Pathak, D. R. Lung cancer risk and vitamin A consumption in New Mexico. *Am. Rev. Respir. Dis.* 131:198-202; 1985.
- State of New Mexico, Environmental Improvement Board. Radiation protection regulations. Radiation Protection Bureau, Santa Fe, NM 87504-0968. Filed April 20, 1980.
- Statistical Analysis System Institute. SAS user's guide: Statistics. Version 5 ed. Cary, NC: SAS Institute; 1985.
- U.S. Department of Commerce. 1982 census of agriculture. Geographic area series of NM. Vol. 1, Part 31. Washington, DC: U.S. Government Printing Office, 003-024-91211-2; 1984.
- U.S. Department of Energy. Environmental Measurements Laboratory procedures manual, 25th ed. New York: Environmental Measurements Laboratory HASL-300; 1982.
- U.S. Nuclear Regulatory Commission. Office of Nuclear Material Safety and Safeguards. Final generic impact statement on uranium milling. Springfield, VA: National Technical Information Service; NUREG-0706, Vol. III; 1980.
- U.S. Nuclear Regulatory Commission. Standards for protection against radiation. Washington, DC: U.S. Government Printing Office; Title 10, Chapter I, Code of Federal Regulations. Part 20 (10 CFR 20); revised as of 1 January 1986.
- Zar, J. H. Biostatistical analysis. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1974.

## APPENDIX A

*Quality control comparisons*

Split samples of muscle, liver, and kidney from six cattle were analyzed for each radionuclide by both laboratories. Eleven analyses were not completed by EPA-Las Vegas due to technical problems. Thus, 97 pairs of split sample results were compared. A range consisting of the reported radionuclide concentration  $\pm$  the counting error was calculated. The ranges overlapped for 56 (58%) of the pairs. For statistical comparison, paired results were grouped by radionuclide and analyzed (Table A-1) using a two-tailed, paired-sample t-test (Zar 1974).

Differences between  $^{210}\text{Po}$  values reported by the two laboratories were significant statistically. Mean  $^{210}\text{Po}$  values reported by Eberline for muscle, liver, and kidney were 1.7, 2.4, and 1.7 times higher, respectively, than those reported by EPA-Las Vegas

(Table A-2). None of the paired-sample t-tests for the remaining radionuclides were significant statistically at the  $p < 0.05$  level of significance.

The one discrepancy between the two laboratories is of particular concern because  $^{210}\text{Po}$  is the radionuclide that contributed most to the internal dose received from eating cattle. Eberline Laboratory reported consistently higher values for  $^{210}\text{Po}$ , although the methods used by both laboratories in determining  $^{210}\text{Po}$  activity were the same. Moreover, both laboratories analyzed the tissue for  $^{210}\text{Po}$  several months after the samples were collected. Thus, laboratory delays in performing  $^{210}\text{Po}$  analyses may have contributed to errors in  $^{210}\text{Po}$  measurements. Polonium-210 has a short half-life of 138 d (Osborne 1963). Both laboratories separated the muscle for  $^{210}\text{Pb}$  and  $^{210}\text{Po}$ . 110 d.

Table A-1. Differences between radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney tissue.

Radionuclide	(N)	Mean Difference (Bq g <sup>-1</sup> ) <sup>a</sup>	SEM (Bq g <sup>-1</sup> ) <sup>b</sup>	t Value <sup>c</sup>	t value required for statistical significance <sup>e</sup>
<sup>235</sup> U	(16)	-0.03	0.03	-1.27	±2.13
<sup>238</sup> U	(16)	-0.02	0.03	-0.69	±2.13
<sup>232</sup> Th	(16)	0.06	0.04	1.38	±2.13
<sup>226</sup> Ra	(18)	-0.28	0.19	-1.48	±2.11
<sup>210</sup> Pb	(15)	0.24	0.69	0.32	±2.145
<sup>210</sup> Po	(16)	3.3	1.2	2.7 <sup>d</sup>	±2.13

<sup>a</sup> Mean difference =  $\frac{\text{(Eberline's reported value - EPA-Las Vegas' reported value)}}{N}$

<sup>b</sup> Standard error of the mean

<sup>c</sup>  $t = \frac{\text{mean difference}}{\text{SEM}}$

<sup>d</sup> Significant at  $p < 0.02$

<sup>e</sup> Two-tailed t value at 0.05 level of significance with N-1 degrees of freedom

almost one half-life, after the animals were sacrificed. Eberline performed the analyses on liver samples 318 and, in one sample, 354 d after collection, and on kidney samples 195 and 200 d post-collection. EPA-Las Vegas analyzed liver and kidney 129 and 101 d after collection, respectively. Although the <sup>210</sup>Po concentrations were corrected for ingrowth from <sup>210</sup>Pb and for <sup>210</sup>Po decay, performance of laboratory analyses several half-lives after

sample collection and mathematical correction of the concentrations to the separation date could introduce error into the results when there is low specific activity in the tissues.

In order to evaluate the differences noted between <sup>210</sup>Po measurements by the two laboratories, we compared <sup>210</sup>Po/<sup>210</sup>Pb ratios reported in this investigation with <sup>210</sup>Po/<sup>210</sup>Pb ratios reported for femurs and soft tissues elsewhere in the literature.

Table A-2. Mean radionuclide concentrations reported by two laboratories for split samples of muscle, liver, and kidney.

Laboratory	Tissue	Mean radionuclide concentrations ± SEM (Bq kg <sup>-1</sup> wet wt.) <sup>a</sup>					
		<sup>235</sup> U	<sup>238</sup> U	<sup>232</sup> Th	<sup>226</sup> Ra	<sup>210</sup> Pb	<sup>210</sup> Po <sup>b</sup>
Eberline	Muscle	0.020 ± 0.003	0.034 ± 0.006	0.021 ± 0.007	0.09 ± 0.06	0.06 ± 0.03	0.56 ± 0.30
EPA-Las Vegas		0.009 ± 0.002	0.008 ± 0.002	0.013 ± 0.004	0.10 ± 0.07	0.06 ± 0.007	0.32 ± 0.13
Eberline	Liver	0.04 ± 0.03	0.05 ± 0.03	0.10 ± 0.07	0.23 ± 0.15	3.3 ± 3.3	58 ± 2
EPA-Las Vegas		0.06 ± 0.04	0.07 ± 0.05	0.04 ± 0.03	0.49 ± 0.35	2.4 ± 1.4	2.5 ± 1.6
Eberline	Kidney	0.16 ± 0.07	0.20 ± 0.09	0.03 ± 0.10	1.2 ± 0.7	2.3 ± 0.5	15 ± 4
EPA-Las Vegas		0.26 ± 0.13	0.26 ± 0.14	0.28 ± 0.14	1.8 ± 1.2	2.3 ± 0.7	8.7 ± 3.0

<sup>a</sup> Standard error of the mean

<sup>b</sup> Eberline's <sup>210</sup>Po reported values were corrected for radioactive decay and for the ingrowth from <sup>210</sup>Pb, to EPA-Las Vegas' (the earlier) separation date.

These ratios in human bone have been reported to approximate 1.0 (Holtzman 1963). However, reported  $^{210}\text{Po}/^{210}\text{Pb}$  ratios in animal femurs have not been found to equal one consistently. In two previous reports,  $^{210}\text{Po}/^{210}\text{Pb}$  ratios in animals' femurs ranged from 0.8 to 23.8 (Table A-3). Average  $^{210}\text{Po}/^{210}\text{Pb}$  ratios in femurs reported by Eberline Laboratory in the present study were from 1.3 to 15.1 in cattle from the three exposed groups and 0.8 among femurs from control cattle (Table A-4). In some cases, these averages are small numbers, primarily because of very low corrected  $^{210}\text{Po}$  concentrations. For example, six of ten individual measurements in control femurs had corrected  $^{210}\text{Po}$  values of zero. EPA-Las Vegas did not perform radiochemical analyses of bone in the present study.

It has been suggested by Osborne that  $^{210}\text{Po}$  may be concentrated in the soft tissues, particularly liver and kidney, of humans and animals, where  $^{210}\text{Po}$  is measurably in excess of  $^{210}\text{Pb}$  (Osborne 1963). He reported  $^{210}\text{Po}/^{210}\text{Pb}$  ratios for the human liver and kidney of 1.8 to 8.9 (Table A-3). Polonium-

$^{210}\text{Pb}$  ratios reported for livers and kidneys of cattle raised in rural areas averaged 2.6 and 4.1, respectively (Bunzel et al. 1979), while ratios in cattle, sheep, and goats exposed to products of the U mining and milling industry, in previous reports (Holtzman 1963; Ruttenber et al. 1984), ranged from 0.2–26 in liver and 0.7–8.9 in kidney (Table A-3).

Most of the averaged  $^{210}\text{Po}/^{210}\text{Pb}$  ratios for muscle, liver, and kidney calculated from values reported by Eberline Laboratory were much higher values than those reported previously and were also higher than those reported by EPA-Las Vegas (Table A-4). Further, the  $^{210}\text{Po}$  concentrations reported by Eberline Laboratory for the exposed and control cattle were higher, both when compared to EPA-Las Vegas measurements and when compared to other published reports. Eberline Laboratory's reported values were approximately twice those of EPA-Las Vegas. The true values for  $^{210}\text{Po}$ , therefore, may have been half those reported in Table 2.

Table A-3. Reported  $^{210}\text{Po}/^{210}\text{Pb}$  ratios in liver, kidney, and bone.

Species	Tissue Type	Exposure To U	$^{210}\text{Po}/^{210}\text{Pb}$ Ratio	Author
Human	Vertebra	unknown	0.8, 0.4	Osborne
	Liver	unknown	3.1, 1.8	
	Kidney	unknown	8.9, 4.1	
Cattle	Femur	exposed <sup>a</sup>	Cow #1-0.9	Holtzman et al.
		control <sup>b</sup>	Cow #3-2.4, Cow #4-0.8	
	Muscle	exposed <sup>a</sup>	Cow #1-3.8, Cow #2-33	
		control <sup>b</sup>	Cow #3-2.9, Cow #4-127	
Liver	exposed <sup>a</sup>	Cow #1-1.1, Cow #2-4.7		
Kidney	exposed <sup>a</sup>	Cow #1-1.6, Cow #2-6.6		
		control <sup>b</sup>	Cow #3-6.9	
Cattle	Liver	not exposed to traffic nor industry	2.6 (average for 27 cattle) range 1.1-9.1	Bunzel et al.
	Kidney	not exposed to traffic nor industry	4.1 (average for 32 cattle) range 1.8-9.2	
Cattle	Femur	exposed <sup>c</sup>	4.2	Ruttenber et al.
	Liver	exposed <sup>c</sup>	10.4, 3.0	
		control <sup>b</sup>	26, 3.3	
	Kidney	exposed <sup>c</sup>	4.6, 5.0	
control <sup>b</sup>		3.6		
Sheep	Femur	exposed <sup>c</sup>	4.3	
		control <sup>b</sup>	2.1, 23.8	
	Muscle	exposed <sup>c</sup>	2.9, 0.42	
	Liver	exposed <sup>c</sup>	0.2, 0.7, 0.7	
	Kidney	exposed <sup>c</sup>	0.7, 5.4, 3.1	
		control <sup>b</sup>	2.5, 6.9	
Goat	Femur	exposed <sup>c</sup>	3.2	
	Liver	exposed <sup>c</sup>	0.3	
	Kidney	exposed <sup>c</sup>	1.2	

<sup>a</sup>Exposed cattle grazed near Anaconda mill in New Mexico.

<sup>b</sup>Control cattle grazed in undisturbed areas of the Grants Mineral Belt, NM.

<sup>c</sup>Exposed animals were from Church Rock, NM.

Table A-4.  $^{210}\text{Po}/^{210}\text{Pb}$  ratios in muscle, liver, and kidney reported by two laboratories.

	Eberline <sup>a</sup>		EPA-Las Vegas <sup>b</sup>	
Ambrosia Lake Group 1	Muscle	58	6.5, 7.2	
	Liver	641	2.6	-
	Kidney	29.5	6,	4.3
	Femur	1.3		
Ambrosia Lake Group 2	Muscle	11.8		
	Liver	247		
	Kidney	5.3		
	Femur	15.1		
Crownpoint	Muscle	13.5	1.3, 1.8	
	Liver	190	-	1.2
	Kidney	9.8		2.2
	Femur	0.8		

<sup>a</sup> Determined by averaging the individual  $^{210}\text{Po}/^{210}\text{Pb}$  ratios for tissues from each animal. All negative and zero numbers for  $^{210}\text{Po}$  or  $^{210}\text{Pb}$  concentrations were set to equal one.

<sup>b</sup> Individual determinations.

#### APPENDIX REFERENCES

- Bunzel, K.; Kracke, W.; Kneuzer, W.  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  in liver and kidneys of cattle. I. Animals from an area with little traffic or industry. *Health Phys.* 37:323-330; 1979.
- Holtzman, R. B. Measurement of the natural contents of RaD ( $^{210}\text{Pb}$ ) and RaF ( $^{210}\text{Po}$ ) in human bone—estimates of whole body burdens. *Health Phys.* 9:385-400; 1963.
- Holtzman, R. B.; Urnezis, P. W.; Padova, A.; Bobula, C. M., III. Contamination of the human food chain by U mill tailings piles. Springfield, VA: National Technical Information Service; NUREG/CR-0758/ANL/ES-69; 1979.
- Osborne, R. V. Lead-210 and polonium-210 in human tissues. *Nature* 199:295; 1963.
- Ruttenber, A. J.; Kreiss, K.; Douglas, R. L.; Buhl, T. E.; Millard, J. The assessment of human exposure to radionuclides from a U mill tailings release and mine dewatering effluent. *Health Phys.* 47:21-25; 1984.
- Zar, J. H. *Biostatistical analysis*. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1974.

**EXHIBIT U**



# THE NAVAJO NATION

Kelsey A. Begaye, *President*

Taylor McKenzie, M.D., *Vice-President*



August 15, 2001

The Honorable Jeff Bingaman  
United States Senate  
Washington, D.C. 20510

RE: Authorization of Appropriation for Demonstration Projects for In-Situ Leach Mining Technologies and Demonstration Projects with Domestic Uranium Producers

Dear Senator Bingaman:

On behalf of the Navajo Nation, we wish to express serious concerns regarding legislation that would provide funding for demonstration projects for in-situ leach mining technologies and demonstration projects with domestic uranium producers. As you know, the U.S. House of Representatives passed legislation regarding this type of funding on August 2, 2001, in H.R. 4, *The Securing America's Future Energy of 2001*. Pursuant to this particular legislation, there would be authorized to the Secretary of Energy \$10 million for each of fiscal years 2002, 2003 and 2004 for demonstration projects for in-situ leach mining technologies and demonstration projects with domestic uranium producers. If the U.S. Senate and President Bush approve this type of legislation, it will most certainly affect the Navajo Nation and the Navajo people.

While Hydro Resources, Inc. may contend that in-situ leaching of uranium is safe; other information appears to show that this is not the case, in particular, when the potential of contamination of underground water is considered. In reviewing the arguments from both camps, those who support in-situ leaching and those who oppose further uranium mining on or near Navajo land, we must take the position that in-situ leaching mining technologies is unproven and that the contention that in-situ leaching is safe is quite inconclusive.

You probably know that:

- An estimated 15,000 people in the Eastern Navajo Agency depend upon the Westwater Aquifer as their sole source of drinking water. This aquifer is currently a very pure source of drinking water with concentrations of uranium ranging from 1-20 ug/L. Uranium mining companies have proposed to use the aquifer for in-situ leaching of uranium.
- In-situ leaching will increase concentrations of uranium in groundwater to the range of 50,000 to 250,000 ug/L.

Letter to Honorable Jeff Bingaman

August 15, 2001

Page two

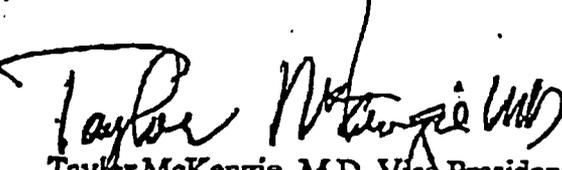
- In the last 30 years, uranium-mining companies have been largely unsuccessful in restoring aquifers after ISL mining.
- Restorations were unsuccessful at a pilot-scale ISL mine operated by Mobil Oil at a site 5 miles west of Crownpoint from 1979-1986.
- The Nuclear Regulatory Commission's (NRC) restoration groundwater standard of 440 ug/L is unsafe.
- The World Health Organization's (WHO) drinking water standard for uranium is 2 ug/L, and the U.S. Environmental Protection Agency (U.S. EPA) recently adopted a standard of 30 ug/L. The NRC standard is 220 times the WHO standard and more than 14 times the U.S. EPA standard.
- There is evidence of kidney damage with uranium levels in drinking water as low as 14 ug/L.
- Even if companies were able to restore the aquifer to the standard set by the NRC, uranium levels would be unacceptably high and communities in the Eastern Navajo Agency would be exposed to a potent nephrotoxin.
- The Navajo people already suffer from high rates of kidney diseases and adding an additional nephrotoxin like uranium to the water supply is an unacceptable risk.

You are aware that uranium mining has proven to be devastating to the health and well-being of the Navajo people, and we trust that you along with us, will assure that this type of devastation from uranium mining will not again be visited on the Navajo people. In view of the information presented here, and other abundant information, casting serious doubt on the safety of uranium in-situ leaching mining technology, we urgently request your assistance in assuring that H.R. 4, or any other form of such legislation is defeated in the United States Congress and does not become law of the land.

With sincere gratitude, we appreciate deeply all you have done for the Navajo Nation and the Navajo people, and with great respect for your position, we sincerely anticipate positive assistance from you on this issue.

Sincerely,

  
Kelsey A. Begaye, President  
NAVAJO NATION

  
Taylor McKenzie, M.D. Vice President  
NAVAJO NATION

Xc: Honorable Edward T. Begay, Speaker, The Navajo Nation Council  
Honorable Robert Yazzie, Chief Justice, The Judicial Branch  
John Hubbard, Area Director, Navajo Area Indian Health Service

January 17, 2005

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION  
ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judges:

Thomas S. Moore, Presiding Officer  
Dr. Richard F. Cole, Special Assistant  
Dr. Robin Brett, Special Assistant

In the Matter of: )  
)  
)

HYDRO RESOURCES, INC. )  
P.O. Box 777 )  
Crownpoint, New Mexico 87313 )  
)

Docket No. 40-8968-ML  
ASLBP No. 95-706-01-ML

DECLARATION OF DR. DONALD A. MOLONY

I, Donald A. Molony, do hereby swear that the following is true to the best of my knowledge. I am qualified and competent to give this declaration, and the factual statements herein are true and correct to the best of my knowledge, information and belief. The opinions expressed herein are based on my best professional judgment.

Name and Purpose of Declaration

1. My name is Donald A. Molony. My mailing address is Department of Internal Medicine, Division of Renal Diseases and Hypertension, University of Texas HSC Houston Medical School ("UTHMS"), 6341 Fannin Street, Houston, Texas 77030. I am giving this declaration on behalf of Eastern Navajo Diné Against Uranium Mining ("ENDAUM") and



Southwest Research and Information Center ("SRIC") related to the licensing of Hydro Resources, Inc.'s ("HRI's") Crownpoint Uranium Project ("CUP"). In particular, I am testifying on whether the Nuclear Regulatory Commission's ("NRC's") secondary groundwater restoration standard for uranium of 0.44 milligrams per liter (mg/l), or 440 micrograms per liter ( $\mu\text{g/l}$ ), is adequate to protect human health in the Church Rock and Crownpoint, New Mexico, areas where uranium *in situ* leach ("ISL") mining would take place.

Professional Qualifications

2. My qualifications to make this declaration are described in my curriculum vitae, a copy of which is appended hereto as **Exhibit A**. I am a professor of Internal Medicine and Nephrology in the Division of Renal Diseases and Hypertension and Center for Evidence Based Medicine and Clinical Epidemiology at UTHMS. I am also the director of Problem-Based Learning at UTHMS and medical director of the Renal Care Group Downtown Dialysis Center in Houston. I have been a participant or member of the national board of the National Kidney Foundation, and for a number of years, I headed the Patient Services Committee of the national board of the National Kidney Foundation, as well as the Kidney Early Evaluation Program, or KEEP, which is a screening program to identify individuals in the population at high risk of kidney disease.

3. I have considerable experience and expertise in matters relevant to the question of the safety of the NRC's secondary restoration standard for uranium for the CUP. In particular, I am a nephrologist — in lay terms, a kidney doctor — actively conducting clinical and basic research. In this research I have studied and published papers on the toxicity of various environmental toxicants, including chlorinated hydrocarbons, and metals such as cadmium,

nickel and uranium, to the mammalian and human kidney. Some of my clinical and research experiences related directly to uranium's nephrotoxicity, and I wish to refer to three of these at this time.

- First, I was an investigator with a team that conducted a case-control study to determine the role of various environmental toxicants exposures including pesticides and metals in the home and work-place to the development of end-stage renal disease. We demonstrated the synergy between various co-morbidities such as diabetic renal disease and progressive renal failure. Thus, moderate degrees of injury from an environmental exposure can produce much more injury in an individual susceptible by virtue of their diabetes, proteinuria, and hypertension.
- Second, my group developed urinary biomarkers in animal models of toxicant- (i.e., hydrocarbons and heavy metals) induced injury that we have related directly to both functional and histopathological findings of renal dysfunction.
- Third, I recently completed an extensive review of the fate of heavy metals such as aluminum and lanthanum in individuals with chronic renal insufficiency. These metals behave similarly to uranium in biological aqueous systems and none of these metals subserve normal enzymatic functions in humans. It is clear that in individuals with any significant degree of renal insufficiency, chronic exposure to even low levels of metals can lead to significant accumulation of these metals in vital tissues of the body.

4. In the summer and fall of 2003, I reviewed the extensive literature on uranium toxicity in preparing my testimony as an expert witness for the New Mexico Environment

Department ("NMED") in support of its petition to the New Mexico Water Quality Control Commission ("NMWQCC") to lower the uranium-in-groundwater standard from 5 mg/l (or 5,000 µg/l) to 0.007 mg/l (or 7 µg/l). A copy of the portion of the hearing transcript that introduces my professional qualifications is appended to this declaration as **Exhibit B** and a copy of the slides I used in giving my direct testimony are appended hereto as **Exhibit C**. I will refer to my slide presentation later in this declaration.

#### Materials Reviewed

5. In preparing this declaration, I reviewed relevant portions of the NRC's *Final Environmental Impact Statement ("FEIS") to Construct and Operate the Crownpoint Uranium Project, McKinley County, New Mexico*, NUREG-1508 (February 1997) (ACN 9703200270), and the source and byproduct materials license, SUA-1508, issued by the NRC to Hydro Resources, Inc. ("HRI") on January 5, 1998 (ACN 980116066). In particular, I read the NRC Staff's rationale for adopting the 0.44 mg/l restoration standard (FEIS at 4-27) and its assertion that this standard, which is based on its radiation protection regulations at 10 CFR Part 20 Appendix B, is protective of human health. I also read License Conditions 10.21(A) and 10.27(A) of License SUA-1508 to understand how this standard will be applied to ISL mining at the CUP. I also reviewed my testimony and slides before the NMWQCC in September 2003, recent published papers on the epidemiology of chronic uranium exposure from drinking water, and the declaration of Dr. John D. Fogarty ("Fogarty Declaration") (January 17, 2005) on behalf of ENDAUM and SRIC. I also reviewed the NMWQCC's Final Order and Statement of Reasons issued upon its adoption of a revised groundwater standard for uranium of 30 µg/l. See, Fogarty Declaration, Exhibit N.

## Professional Opinion and Analysis

6. Based on my knowledge of the affects of trace metals, including uranium, on the proximal tubules and thick ascending limb of the human kidney, and on my knowledge and review of the relevant published medical and epidemiological literature, I believe that the NRC's secondary groundwater restoration standard for uranium of 0.44 mg/l is not protective of public health. I believe that the NRC erred in adopting a *radiation protection standard* for uranium when the adverse affects of chronic exposure to uranium in drinking water are clearly related to uranium's *chemical toxicity* to the human kidney. I further find that the NRC was wrong to adopt a groundwater restoration standard that is arguably almost two orders of magnitude too high in an area when the local population depends exclusively on groundwater for its drinking water and to sustain their livestock (see, FEIS at 3-22 to 3-24) and where the current rates of kidney disease are already more than four times greater than the national average (see Fogarty Declaration, ¶ 44 at 34-35). Since License Condition 10.21(A) applies the 0.44 mg/l restoration standard for uranium to groundwater restoration at all three mining sites that are the subject of this proceeding (i.e., Section 17, Unit I and Crownpoint), my conclusions and analysis are applicable to all three sites.

7. In support of these conclusions, I first drew from my medical training and early research interests. In particular, after earning my medical degree at the University of California San Diego Medical School, I spent six years in postdoctoral training, three of these in basic research training in renal physiology, completing preliminary work on the transport properties of the proximal tubule and the cortical collecting tubule, which are the segments of the kidney nephron damaged by uranium exposure. (See, eg., Exhibit C, Slides 21-22.) I investigated for

most of the last 15 years the function of the thick ascending limb, which is the nephron segment that follows the proximal tubule and which is also a site of toxicant induced injury. I have discovered that this portion of the kidney nephron is also affected by a number of environmental agents, especially heavy metals, and that the injury in this segment interacts with the injury and dysfunction in the proximal tubule and collecting duct.

8. Over the past 30 years, the medical community has gained considerable knowledge in how trace metals like uranium affect the function of the proximal tubules and thick ascending limb. The proximal tubules and thick ascending limbs are but two of the essential segments of the cell-lined, continuous microscopic tube (or, "tubule") that make up each of the 1 million of so nephrons in the human kidney. See **Exhibit C**, Slides 21-22; see, also, Fogarty Declaration, **Exhibit B**, Slides 6-7. They are critical for the function of the kidney since the cells that line these segments mediate absorption and secretion of ions, proteins, and other organic molecules that ultimately determine the final composition of the urine. See **Exhibit C**, Slide 23. These nephron segments are, therefore, central to the kidney's function of regulating all fluids within of the body and their composition. Central to this function is the capacity of these nephron segments to absorb substances that the body must conserve and clean substances that the body must get "rid of." See **Exhibit C**, Slides 27-28.

9. These tubular functions are impaired by the injury that is caused by metals. Metals injure the cell lining the tubules in two principle ways. First, the metals may interact with the transporters that regulate absorption and interfere directly with the cellular energetics and function. More important, these metals are absorbed through the normal transporters into the cells where they have a number of deleterious effects on intracellular processes. See **Exhibit C**, Slides 25-28.

These include the effects of uranium on mitochondrial electron transfer, adjuncts of metals and proteins forming within the cytoplasm, and the effects of uranium on metalloproteinases (one of the principle defenders of the cell from oxidative stress and oxygen free radicals). These effects are related to the metal properties of the uranium and are not at all related to any radioactivity of uranium. Radioactive uranium's effects will include DNA damage and may be more intense within the kidney than elsewhere because of the concentrating capacity of the kidney.

10. The intracellular accumulation of the metal uranium, if chronic and prolonged, or if of sufficient magnitude over even short periods, will overwhelm the kidney cells' capacity for repair. See Fogarty Declaration, Exhibit B, Slide 17. Furthermore, if the kidney tubular cells are already stressed by diabetic proteinuria or other co-morbidities (Exhibit C, Slides 30 and 39), their capacity to defend against the effects of uranium will be limited further.

11. Recent population-based studies in Canada and Finland show clearly that even low doses of uranium are associated with subclinical adverse effects on the proximal tubules. These findings are entirely predictable given the scientific and medical community's evolving knowledge of the effects of uranium on the proximal tubular cell. As I mentioned in my direct testimony and slides before the NMWQCC, abnormally high levels of certain low-molecular weight proteins and cellular enzymes were detected, in a dose dependent manner, in the urine of people who drank water containing uranium in concentrations ranging from 0.014 mg/l (or 14 µg/l) to 0.028 mg/l (or 28 µg/l). See Exhibit C, Slide 46; see, also, Mao, et al., 1995; Zamora, et al., 1998; and Kurttio, et al., 2002, attached as Exhibits F, G, and H, respectively, to Fogarty Declaration. The presence of abnormal levels of these biomarkers indicate that the functional capacities of the tubules are impaired, including their ability to reabsorb proteins, and that

tubular cells are dying off by necrosis and apoptosis, releasing these biomarkers into the urine. Cell death occurs as a consequence of the presence of the uranium metal molecules.

12. As summarized in detail in the Fogarty Declaration (¶¶ 26-29 at 17-21), these and other population-based studies in the last 20 years have become the basis for the progressive *lowering* of health-based drinking water standards and guidelines for uranium. The World Health Organization (“WHO”) recommends a maximum contaminant level of 0.002 mg/l (or, 2 µg/l) and Health Canada recently revised its national guideline for uranium downward from 0.1 mg/l (or, 100 µg/l) to 0.02 mg/l (or, 20 µg/l). (See, Fogarty Declaration, Exhibits M and L, respectively.)

13. In my testimony before the NMWQCC, I supported NMED’s proposed groundwater protection standard of 0.007 mg/l (or, 7 µg/l) because I believe it was an evidence-based, thorough and rigorous analysis of the published literature on uranium toxicity, the physiological and chemical processes that take place in the kidney, and the special conditions with respect to daily water intake among rural populations in New Mexico. See, Exhibit C, Slide 49. Subsequent to the public hearing I participated in, the NMWQCC adopted a standard of 30 µg/l (see, Fogarty Declaration, Exhibit N, ¶ 41 at 29), which is identical to the national drinking water standard adopted by the U.S. Environmental Protection Agency (“USEPA”) in December 2000. (See, Fogarty Declaration, Exhibit D.) In its rationale for adopting a uranium drinking water standard in December 2000, the USEPA acknowledged that it raised the maximum contaminant level for uranium from its 1991 proposed level of 20 µg/l to the adopted level of 30 µg/l in part based on its analysis of the costs and benefits of compliance. See Fogarty Declaration, Exhibit D at 76714. It is my professional opinion, however, that these agencies

professional opinion, however, that these agencies would have been justified to have adopted an even *lower* uranium standard based purely on the medical and epidemiological evidence. In other words, a standard of 30  $\mu\text{g/l}$  — of a level *nearly 13 times lower* than the NRC's proposed secondary restoration standard for uranium — may not be entirely protective of kidney health, especially in a population such as that on the Navajo Nation where kidney health is already compromised. See Exhibit C, Slide 16.

14. I concur with Dr. Fogarty's explanation of how actual exposure to drinking water containing 0.44 mg/l (or, 440  $\mu\text{g/l}$ ) could take place at the CUP, especially in the town of Crownpoint. Furthermore, I endorse Dr. Fogarty's testimony as an accurate and rigorous explanation of the relevant literature on uranium toxicity.

15. This concludes my testimony.

Pursuant 28 U.S.C. §1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the Seventeenth day of January 2005.



Donald A. Molony, MD

# EXHIBIT A

## CURRICULUM VITAE

**NAME:** Donald A. Molony, M.D.

**PRESENT TITLE AND AFFILIATION:** Professor of Medicine  
Department of Internal Medicine  
University of Texas Houston Medical School

**Other appointments:** Associate Professor of Toxicology 1994 - 1998, 1999 - 2000,  
Graduate School of Biomedical Sciences  
University of Texas-Houston  
and  
Associate Professor of Physiology and Cell Biology 1992 - 1998  
University of Texas-Houston Medical School  
and  
Professor, Medical Subspecialties (2001- present)  
M.D. Anderson Cancer Center (1986 - present)

**OFFICE ADDRESS:** University of Texas Medical School  
Department of Internal Med / Division of Renal Diseases and Hypertension  
MSB 4.128  
6431 Fannin Street  
Houston, Texas 77030  
**Telephone:** (713) 500-6872  
**FAX:** (713) 500-6882  
**Email:** Donald.A.Molony@uth.tmc.edu

### Education:

**UNDERGRADUATE-** B.S. with departmental honors in Biology,  
Yale University, New Haven, CT 1970-74

**GRADUATE-** M.D., University of California, San Diego,  
Medical School, La Jolla, CA, 1974-78

### POSTGRADUATE TRAINING:

1978-1979 Internship, University of Texas Health  
Science Center at Dallas, and Parkland  
Memorial Hospital/Dallas, Texas  
Director: Donald Seldin, M.D. 1979-1981

1979 - 1981 Residency in Internal Medicine, University of  
Texas Health Science Center at Dallas, and  
Parkland Memorial Hospital/Dallas, Texas  
Director: Donald Seldin, M.D.

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

1981-1984 Nephrology Post-Doctoral Fellow, University  
of Texas Health Science Center at Dallas and  
Southwestern Medical School  
Director: Juha P. Kokko, M.D.-Ph.D.

**ACADEMIC APPOINTMENTS:**

1984 - 1992 Assistant Professor of Medicine, The University  
of Texas- Houston, Medical School  
Chairman: Thomas E. Andreoli, M.D. (1984 - 1988)  
James T. Willerson, M.D. (1990 - present)

1992 - 2001 Associate Professor of Medicine,  
University of Texas-Houston Medical School  
Chairman: James T. Willerson, M.D.

2001-present Professor of Medicine,  
University of Texas-Houston Medical School  
Department of Internal Medicine  
Chairman: Frank Arnett, M.D. (2001 – 2004)  
Bruce C. Kone, M.D. (2004 – present)

1991 - 1998 Toxicology Program, Graduate School of Biomedical Sciences,  
University of Texas-Houston  
Dean: R.W. Butcher, Ph.D.

1993 - 1998 Associate Professor of Physiology and Cell Biology, University of Texas-  
Houston, Medical School  
Chairman: Stanley G. Schultz, M.D.

1994 - 2002 Associate Professor, Medical Subspecialties  
M.D. Anderson Cancer Center  
Chairman: W. Body, M.D.

1994 - 2002 Professor, Medical Subspecialties  
M.D. Anderson Cancer Center  
Chairman: R. Gagel, M.D.

**Curriculum Vitae  
Donald A. Molony, M.D.**

1995 - 2000                      Member of Clinical Epidemiology Section  
   Director: John Ribble, M.D.

1999- present                      Center for Population Studies and Evidence Based Medicine  
   Center for Clinical Epidemiology and Evidence Based Medicine  
   Director: Jon Tyson, MD, MPH

**HOSPITAL AND CLINIC APPOINTMENTS:**

1984-Present                      Hermann Hospital; Medical Staff  
   M.D. Anderson Cancer Center; Medical Subspecialties

1985 – 2004                      University Kidney Center Dialysis Units – UKC South

1987 - 1996                      Diagnostic Hospital; Medical Staff

1989 - present                      Harris County Hospital District, LBJ Hospital.

2000 - present                      Renal Care Group Downtown Dialysis Unit

2000 - 2001                      Total Renal Care Dialysis Units Houston Region

2001 – present                      Davita Houston Region

2000 - 2004                      Christus- St Joseph's Hospital

2000 - present                      St. Lukes Hospital

2000 - 2004                      Park Plaza Hospital

2003 – present                      Methodist Hospital- Houston

**LICENSURES - Active:**

Texas State Board of Medical Examiners #F9841  
Date issued: 09/23/81

**- Inactive:**

California Board of Medical Quality Assurance  
Date issued: 1/12/81

**SPECIALTY BOARD CERTIFICATION:**

American Board of Internal Medicine  
Board Certified in Internal Medicine Sub-specialty Board of Nephrology  
Date issued: 9/83                      Date issued: 11/11/86

**PROFESSIONAL ORGANIZATIONS (AND COMMITTEES OF THESE): LOCAL AND REGIONAL**

National Kidney Foundation of Southeast Texas  
Medical Advisory Board                      1988 - present  
   Chairman (MAB-NKF of SET)                      1989-1992  
   Fellowship Committee (NKF of SET)                      1993 - 1994, 1996 - 1999

National Kidney Foundation of Southeast Texas -

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

Board of Directors	1989 - 2000
Executive Committee	1992 - 1999
NKF-SET Vice President	1993 - 1994; 1996 - 1998
Texas Medical Foundation- Physician Consultant	1991 - 1994
Medical and Scientific Advisory Board;	1991 - present
Lupus Foundation of America; Houston Chapter	
Gulf Coast Nephrology Association; Sect-Treasurer	1993 - 1995
Vice President	1995 - 1997
American Heart Association - Houston Health Objectives 2000	
Cardiovascular Working Group - Blood Pressure Awareness & Screening.	1992 - 1996

**NATIONAL COMMITTEES:**

**National Kidney Foundation, National-**

Patient Services Committee 1993 -1995; 1996 - 1999

**National Chair - NKF National Patient Services Committee** 1997 - 1999

Committee was responsible for developing or initiating 4 new national programs including: RISE (rehabilitation program), People-like-us-live (pre-renal failure education program), PEER (peer to peer counseling), KEEP (early evaluation and intervention)

Also developed: Patient Handbooks - Published by the NKF and Amgen  
 Advanced Directives - Handbooks and Sample forms.

**K.E.E.P (Kidney Early Detection and Education Program - NKF National)**

**National Chair** 1996 - 1999

Developed case identification program for identification of individuals at high risk for developing renal failure, conducted screenings - 20 cities to date with 1100 participants, analysis of the data - Funding by Pfizer Inc \$750,000 to NKF National

NKF- Early Intervention Task Force 1994 - 1998

NKF- Planned Giving Committee 1993 - 1994

NKF- National Medical Advisory Board

Nominating Committee 1995 - 1996

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

**PROFESSIONAL ORGANIZATIONS (AND COMMITTEES OF THESE): NATIONAL: CONTINUED:**

NKF Task Force on Reuse – National Advisory Committee	1998
Revised technical guidelines / made recommendations for the Institute of Medicine	
NKF - National Board of Directors	1996 – 1999
Board Member: elected –at – large to 3 terms	
National Kidney Foundation - Town Meeting Planning Group	1992 - 1993
<b>National Board of Medical Examiners:</b>	
Member Step 3 Item Writing	
Task Force on the Use of the Medical Literature.	1998
Step 3 Acute Care committee	1999 – 2001
<b>United States Endstage Renal Disease Network-14</b>	
Medical Review Board	2004

**Society Memberships:**

American College of Physicians	American Society of Nephrology
New York Academy of Science	International Society of Nephrology
American Physiological Society	National Kidney Foundation
American Federation of Clinical Research	
American Medical Association	

**HONORS AND AWARDS:**

Harvard Macy Institute: Program for Physician-Educators; Scholar 1996  
National Kidney Foundation of Southeast Texas  
    Chairman, MAB 1989-1992  
    Special Recognition: 1992.  
Best Teacher, Fundamentals of Clinical Medicine 1992  
Special recognition from the class of 1998-End of Basic Sciences Awards  
Banquet 1996: "Renaissance award"  
Special recognition from the class of 1999-End of Basic Sciences Awards  
Banquet 1997: "Most Supportive Course Director."  
Deans Teaching Excellence Award 1989- 1992, 1994, 1996 - 2004  
Marshall, University Honors Convocation, 1992  
Walter Kirkendahl Award, 1994  
UT-Houston Masters Teacher Award 2002-2005

**EDITORIAL POSITIONS:**

American Journal of Kidney Diseases - CME Section Editor      1998 - 2001

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

**Reviewer for Journals:**

American Journal of Kidney Diseases; CME-editor	
J. Am. Soc. Nephrol.	J. Clinical Investigation
Kidney International	J. Toxicol & Appl. Pharm.
American Journal of Physiology	Circulation

**SERVICE ON NATIONAL GRANT REVIEW PANELS, STUDY SECTIONS, COMMITTEES:**

**Reviewer Grants:**

American Heart Assoc. - Texas: Research Grants	1994-1996, 1997-1998
Dept. Veterans Affairs - Merit Review Applications	1994
National Kidney Foundation of SET Fellowship Applications	1995 – 2002
National Kidney Foundation of National Fellowship Awards Program	2004
Southwestern Center for Occupational & Environmental Health NIOSH Pilot Research Training Program	2003, 2004
NIH-NIDDK –Ad hoc Study Section: Research Grants for Clinical Studies of Kidney Diseases (August 19 – 20, 2004)	2004

**SERVICE ON THE UNIVERSITY OF TEXAS-HOUSTON HEALTH SCIENCE CENTER COMMITTEES:**

-Institutional Task Force on Contracts & Grants	1989 – 1993
Charged with reviewing and reforming the processes involved in the institutional review and approval grants and contracts	
-Special Advisory Committee to President Low, Joint Committee for Assessing the Recommendations of the Strategic Directions Task Forces	1992 - 1994
-School of Allied Health Sciences Program Review Com.	1994-1995
Charged with determining the procedures used for downsizing of the Sch of Allied Health and for the termination of non-degree programs.	
SACS Self-study - Content Team	1998 - 1999
Special Advisory Team Hightower High Sch; Distance Learning Wellness Program	1998
Review and update of Hightower HS Programs	2004
Review Committee; 5 year review of the Dean of the Medical School	2002

**Curriculum Vitae  
Donald A. Molony, M.D.**

**SERVICE ON THE UNIVERSITY OF TEXAS-HOUSTON MEDICAL SCHOOL COMMITTEES:**

Dean's Ad Hoc Committee on Compensation	5/00 – 9/01
Biweekly meetings and outside consultation to develop a Medical School compensation plan; Representing the faculty	
President, Faculty Senate (three terms)	1999–2000 & 1992-1994
Organized the agenda for monthly meetings Maintained communications between faculty and administration Serve as the faculty representative to various university advisory boards and committees; compile the annual reports	
President elect, Faculty Senate	1998 – 1999
Faculty Representative to Administrative Council	1992–1994, 1999–2000
Vice President Faculty Senate	1991 - 1992
Faculty Senate Representative	1988–1994;1996-present
Medical Quality Assurance Committee	1989 - 1992
<b>Nephrology Fellowship Evaluation committee</b>	1991 – present
Quarterly meetings to review and evaluate progress of fellows in training and to review and evaluate policies and programs and requirements of the fellowship	
<b>Director, Div Renal Diseases &amp; Hypertension Ambulatory Clinic</b>	1999 – 2003
Responsible for setting policies for professionals and to advise clinic administration on issues related to clinic operations	
University of Texas-Houston; Medical School - Quality Council	1993 -1995
Task Force on Educational Initiatives	1992 – 1997
- Charged with developing new educational programs for the Medical School	
Problem Based Learning (PBL) Steering Committee	1992 – 1997
Educational Committee, Department of Internal Medicine	2001 - present
<b>Problem Based Learning Executive Committee</b>	1996– present
<b>PBL Case Writing and Working groups:</b> (Each working group charged with developing the block learning objectives, writing and editing PBL cases and examination questions):	
Cardiovascular Core	1993 - present
Principals Core	1993 - present
Renal Core (chair, working group)	1994 - present
Infectious Diseases Core	1994 - 1997
Neurology Core	1996
<b>Director of Problem-Based Learning,</b> <b>University of Texas HSC Houston Medical School</b>	2003 - present
University of Texas Houston Medical School	

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

<b>Curriculum Committee</b>	1993 – 2000
Task force on the 3 <sup>rd</sup> and 4 <sup>th</sup> year curriculum	1999 – present
Vision Committee; Advisor and Reviewer	1999 – 2003
Vision Committee- member	2003 - present
<b>Graduate Education Committee – Medical Sch</b>	
– Toxicology Program representative	1999 - present
<b>Clinical Epidemiology Section</b>	1995 – present
Curriculum development for Clinical Epidemiology yr 1- 4	2002- present
Curriculum development committee for the Clinical Epidemiology course for the 4 <sup>th</sup> year medical students	1995 - 1999
<b>SERVICE ON GRADUATE SCHOOL COMMITTEES:</b>	
<b>Environmental and Occupational Health Educational and Research Center - Renal Section; Co-Chair</b>	1991 - present
- Helped coordinate curriculum in this specialized interest area, participate in graduate student seminars and journal club. - Participant in the Toxicology training grant	
<b>Toxicology Graduate Program- Graduate student review committee</b>	1994 - present
Review applications for training grant positions and student progress on the training grant	

**SERVICE TO THE COMMUNITY:**

**Medical Director: Renal Care Group- Downtown Dialysis Unit**      2000– present  
Responsible for establishing all patient care protocols and reviewing and updating protocols in a timely fashion, maintaining quality of professional staff through checks and audits, reviewing and participating in monthly quality assurance reviews and variance audits; reviewing the qualifications of medical and technical personnel, reviewing technical aspects of the dialysis unit including insuring the proper completion of reuse, water quality, etc  
Federal oversight agencies estimate that fulfillment of these responsibilities will require that the medical director devote **30 – 40 hours per week** to these tasks.

**SPONSORSHIP OF CANDIDATES FOR POSTGRADUATE DEGREE:**

Advisory and Supervisory Committees for:

Alan Lee Biddinger, Candidate for Ph.D. GSBS June 1997  
Thesis: "Genes to Blood Pressure. The effects of variation in genes of the renin-angiotensin system on the hormonal and renal control of blood pressure."

Alison Stock, Ph.D., MPH Candidate for Ph.D SPH 1999

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

Thesis: On mechanisms of pesticide injury in the distal nephron.

Rodney Beaty, Candidate for Ph.D. - GSBS - 2001

Thesis area: Mechanism of apoptosis induced by pesticides in nephron segments.

Joel Bercu, Candidate for MS SPH, June 2001

Thesis title: Compounds that bind to the GABA / benzodiazepine ionophore complex modulate the cellular response to oxidant stress.

Binu Asha George, MPH

Work completed under the direction of Dr. Jan Rissor and Dr. Donald Molony

Thesis: Systemic review of treatment options for immunoglobulin A nephropathy

Submitted 7/23/01 for fulfillment of the requirements for a Masters of Public Health

Role: Supervising professor

Joshua A Samuels, M.D., Candidate for MPH SPH December 2002.

Thesis: A Meta-analysis of immunosuppressive treatment of IgA Nephropathy

Role: Thesis Supervisor

**TEACHING RESPONSIBILITIES:**

5/91- 12/2003 - **Course Director: Fundamentals of Clinical Medicine (FCM).**

Created Course and directed since inception as a bridging course between the basic science and clinical years. Course was modified in 1994 to allow for the introduction of the Problem-based-learning curriculum.

Course content: clinical correlates to pathophysiology; approximately 150 hours of instruction involving more than 120 faculty. The course includes lectures, critical appraisal exercises, and the problem-based learning curriculum. The course director is responsible for organizing the lectures and small groups, compiling and editing the syllabi and the comprehensive examinations (5-7 examinations / year). The course director is responsible for resolving student problems and briefing and evaluating the faculty – Course duties occupy on average 6 hours of dedicated time per week.

8/2003 – present- **Director of Problem-Based Learning**

7/2004 – present **Course Director: Integrated Clinical Experience / Problem-based learning**

8 /2003 – 12/03 **Course Director: Using Research to Inform Health Care Policy and Practice;**  
4 hour graduate level course taught as part of the Masters Program in Clinical Study Design,

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

Center for Evidence Based Medicine and Clinical Epidemiology, University of Texas HSC  
Houston

**1/94-present- Problem Based Learning Curriculum**

Course Director FCM / PBL Curriculum (1994 – 12/2003).

Planning Group, PBL Oversight Comm., Evaluation Comm., Working Groups in  
Cardiovascular, Renal, and Principles. Advisory status to working groups in Neurology,  
infectious diseases, and endocrinology.

1994-present Facilitator in **PBL** (1 -2 blocks per year; eight weeks each block; this involves 6 plus  
hours of small group interaction with students per week, preparation to teach the PBL  
cases and time to debrief and evaluate the student's performances) – approximately 80  
hours per block

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

**TEACHING RESPONSIBILITIES: (Continued):**

9/91-present	-	<b>Fundamentals of Clinical Medicine lectures:</b>	
		Hypertension - Rational approach to hypertension therapy (1 hour)	1991 - 1997.
		Toxicology and Medical complications of ethanol use (2 hours)	1991 - 1994
		Fluid and Electrolytes: Na and water metabolism (2 hours)	1991 - 2003
		Electrolytes I: Na and H <sub>2</sub> O (1 hour)	2004
		Potassium metabolism (1 hour)	1991 - 2003
		Electrolytes II: K, Mg, PO <sub>4</sub> (1 hr)	2004
		Calcium and Phosphorous metabolism (1 hour)	1993
		Syndromes in Nephrology (1 hour)	1993- 2003
		Acute and chronic renal failure (1 hour)	2000
		Biostatistics (1 to 3 hours)	1997 -1998
		Critical Appraisal of Therapy Studies (1 hour)	1996 - 2003
		The Well-built clinical question (1 - 3 hours)	1997 - 2003
		Acid Base Disorders (2 hours)	2000- 2003
9/91- 6/94		<b>Fundamentals of Clinical Medicine</b> Small Group leader (Prior to the introduction of PBL which replaced the small groups): Clinical Reasoning small group discussions (Small groups 16 hours/year).	
2004 - present		<b>ICE - PBL lectures:</b>	
		Critical Appraisal of Therapy Studies (1 hour)	2004 - present
		The Well-built clinical question (1 hour)	2004 - present
		Critical Appraisal of Systematic reviews	2004 - present
1995- present		<b>Evidence Based Medicine Workshop</b> McMaster University, tutor trainee 1996; tutor 1997, 1998, 1999, 2000, 2003	
1996 - 1999		<b>Clinical Epidemiology / Evidence Based Medicine</b> Required Course for fourth year students (March month); Member of planning committee, facilitator for the faculty training course to train faculty as teachers of EBM (1996, 1997), and facilitator in the student directed course, 1996, 1997, 1998, 1999. Later involved 9 - 12 hours of small group teaching with 20 - 30 4 <sup>th</sup> year students.	
1991 - present -		<b>Physical Diagnosis</b> (2 <sup>nd</sup> year curriculum): small group (2-3 students) preceptor Each session (5 - 7 weeks; 2 -4 hours per week) for direct interaction with students and grading of history write-ups. 1 session 1991 -1996, 2000; 2 sessions 1998, 1999, 2001 - 2003	

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

1985- present - **Attending in Nephrology/General Medicine, 5-7 months/ year attending in Nephrology/1 month Medicine per year (1985 to 1990, and 2000-2001) and 6-9 months Nephrology per year (1990 - 1998) and 4 months Nephrology (2002 to present).**

**TEACHING RESPONSIBILITIES: (Continued):**

1996 - 2001 Examiner - First, second, or fourth year **OSCE examinations.**

1997 - 2000 - Internal Medicine Board Review - Clinical Epidemiology / Critical Appraisal (30 – 45 minutes).

1991 - present **Graduate Seminar in Toxicology; Renal toxicology and Research Seminars (1 - 2 hour/year).**

Toxicology Graduate Seminar, Journal Club (summer semester).

1990-2002 - **Nephrology Core Curriculum (3 - 6 hrs lectures/yr).**

1990-present - **CPC conferences for Internal Medicine;**

1990 - Polycystic Kidney Disease

1992 - Acute Renal Failure after Pesticide Exposure

1993 - Membranous Glomerulonephritis

1993 - Tuberos Sclerosis

1994 - Tubulointerstitial Nephritis / Analgesic Nephropathy

1994 - Wegner's Granulomatosis

1996 - Membranous Glomerulonephritis

1997 - Glomerulonephritis

1997 - Membranous Glomerulonephritis

1999 - Acyclovir nephrotoxicity (4/99)

1999 - Mercury Poisoning

1984-present - **Grand Rounds in Internal Medicine;**

1984 - Hyperkalemia.

1987 - Disorders of Renal Concentration and Dilution.

1989 - Toxic Nephropathies.

1994 - Analgesic nephropathy

1999 - Proteinuria / Hematuria: Early markers; modifiable risk factors.

**Grand Rounds Internal Medicine – MD Anderson**

2002 - Uremic Arteriolar Calcification

**Grand Rounds in Cardiology;**

1997 – Hypertension

**Grand Rounds CV Surgery**

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

**Renovascular Hypertension**  
**Grand Rounds in Pediatrics;**  
**1997 - Pediatric toxic nephropathies**

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

**TEACHING RESPONSIBILITIES: (Continued):**

**Grand Rounds; Division of Renal Diseases and Hypertension:**

- 2000 – IgA Nephropathy
- 2001 – Renal Diseases in Special Populations
- 2001 – Recent Advances in IgA nephropathy
- 2002 – The Loop of Henle
- 2002 – Tubulointerstitial Disease
- 2002- Calcium-Phosphorus management for optimal renal failure outcomes
- 2003 –New Insights into the Cardiovascular Calcium Mortality Connection

- 1990 - 1995 - **Pharmacology Core Curriculum 2<sup>nd</sup> yr: Clinical Pharmacology of Hypertension; (1 - 2 hr/yr) and Emergency Management of Hypertension including Malignant Hypertension. (1 hour/ year).**
- 1986-1997 - **Pathology Core Curriculum 2<sup>nd</sup> yr: Renal CPC; (2 hours/yr).**
- 1992 - 1998 - **Nephrology Journal Club (4 - 6 hours / year).**
- 1993 - 1995 - **Department of Emergency Medicine; Emergency Medicine Lecture series: Renal Emergencies (2 hours).**
- 1991-1994. - **Cardiology Fellowship Core Curriculum: Lectures on Hypertension.**
- 1993 & 1994 - **Preventive Cardiology Course; Lectures on Hypertension.**
- 1992-1998 - **Internal Medicine Residency Core Curriculum (1 - 3 hours/year).**
- 1989-1992 - **Renal Physiology Journal Club / Co-sponsored by Physiology and Cell Biology and Internal Medicine - Nephrology.**
- 1986-1990 - **Mechanisms of Disease (sophomore overview course antedated FCM): Renal lectures (5 hours/yr).**
- 1985-1990 - **Introduction of Clinical Medicine (antedated physical diagnosis): Small Group Preceptor.**
- 1989-1991 - **3rd Year Core Clerkship in Internal Medicine: Fluid and Electrolyte Lectures (8 hrs/yr).**
- 1986-1991 - **Department of Internal Medicine; Emergency Medicine Lecture series: Electrolyte emergencies.**

**GRANT SUPPORT; CURRENT:**

- 2000-2004 **NIH - NIEHS**  
**Mechanisms of pesticide induced distal nephron injury.**  
**March 1, 2000 -Feb 28, 2004**  
**\$686,609 direct costs**

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

2000 - 2005            NIH - NHLBI  
Development of a longitudinal nutritional curriculum  
P.I.    Marilyn S. Edwards, Ph.D.  
4-1-00 to 3-31-05  
Co-investigator; Support: None

**PAST GRANT SUPPORT:**

1989-1990            Biomedical Research Support Grant - University of Texas Medical School at Houston  
April 1, 1989 - March 31, 1990  
\$9,000

1989-1990            American Heart Association - Texas Affiliate  
July 1, 1989 - December 31, 1990  
\$30,250

1991-1992            Pfizer Pharmaceutical  
June 1, 1991 - November 30, 1992  
\$22,000

1991-1992            Amgen, Inc.  
June 1, 1991  
Direct costs: \$8,000

1990-1994            American Heart Association  
Grant-in-Aid: July 1, 1990 - June 30, 1994  
Direct costs: \$115,500.

1991-1996            Environmental Protection Agency  
July 11, 1991 - July 10, 1996;  
Direct costs \$381,403

1994-1997            Amgen, Inc.  
The Effects of Normal versus Anemic Hematocrit on Outcomes of Cardiac Disease in  
Dialysis Patients - AMGEN protocol 930107  
March 1, 1994 - July 28, 1997 - \$165,000

1996 - 1997            Pfizer Inc.  
Research Grant – Investigator initiated.  
Cytoprotective effects of calcium channel anatagonists in a model of distal nephron injury

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

due to nephrotoxicant exposure or ischemia.  
\$15,000

1994-2002 National Institutes of Health – NHLBI  
Antihypertensive and Lipid-lowering Treatment to Prevent Heart Attack Trial  
(ALLHAT) - Vanguard Center (P.I. for vanguard center; Carlos Herrera, M.D.) - co-  
investigator  
Support: None

1996-2001 National Institutes of Health - NIEHS  
Joint Training Program to Study Toxic Mechanisms  
P.I. Andrij Holian, Ph.D., David McConkey, Ph.D  
Co-investigator; Support: None

**ACTIVE CLINICAL RESEARCH PROTOCOLS:**

Obstructive sleep apnea and progression of renal disease.

P.I.: Richard Castriotta

Sleep disorders in end-stage renal disease.

P.I.: Richard Castriotta

Do insecticides cause kidney failure? A case-controlled study.

P.I. Donald Molony

**Bibliography**

**Abstracts**

1. Molony, D.A., Kokko, J.P., Seldin, D., and Jacobson, H.R.: Acid peritubular pH suppresses sodium reabsorption in cortical collecting tubules. *Kidney Int.* 25 (10):279D, 1984.
2. Molony, D.A., Kokko, J.P., Seldin, D.W., and Jacobson, H.R.: Electrophysiologic measurements demonstrate two distinct populations of rabbit cortical collecting tubule (CCT) cells. American Federation of Clinical Research Conference, Washington, D.C., May, 1984.
3. Molony, D.A., Kokko, J.P., Seldin, D.W., and Jacobson, H.R.: Mechanisms of suppression of cortical collecting tubule (CCT) sodium absorption by peritubular acidosis; physiological evidence for two populations of cells. IXth International Congress of Nephrology Conference, Los Angeles, California, June, 1984.

## Curriculum Vitae

Donald A. Molony, M.D.

4. Molony, D.A., Kokko, J.P., Seldin, D.W., and Jacobson, H.R.: Electrophysiologic measurements demonstrate two distinct populations of rabbit cortical collecting tubule (CCT) cells. *Clin. Res.* 32(2):534A, 1984.
5. Molony, D.A., Reeves, W.B., Hebert, S.C., and Andreoli, T.E.: Antidiuretic hormone (ADH) increases cellular ( $g_b$ ) in mouse medullary thick ascending limb (mTALH) by increasing apical salt entry. *Clinical Res.* 34:303A, 1986.
6. Reeves, W.B., Molony, D.A., and Andreoli, T.E.: The contribution of Cl<sup>-</sup> conductance ( $g_b$ ) to basolateral conductance ( $g_b$ ) in mouse medullary thick ascending limbs (mTALH). *Clinical Res.* 306A, 1986.
7. Molony, D.A., and Andreoli, T.E.: Peritubular hypertonicity reduces transcellular electrical conductance and hyperpolarizes basolateral membranes if isolated mouse medullary thick ascending limbs (mTALH). *Kidney Int.* 31:439, 1987.
8. Molony, D.A., and Andreoli, T.E.: Peritubular hypertonicity inhibits directly basolateral membrane chloride conductance ( $g_b$  Cl) in the isolated mouse medullary thick ascending limb (mTALH). *Clinical Res.* 35:553A, 1987.
9. Molony, D.A.: Flurazepam (FLZP) antagonizes the response of the mouse medullary thick ascending limb (mTALH) to peritubular hypertonicity. *Kid. Int.* 33:422, 1988.
10. Molony, D.A., and Andreoli, T.E.: Conductive characteristics of individual basolateral membranes in mouse medullary thick ascending limbs (mTALH): Basolateral membranes are goldman-like rectifiers. *Clinical Res.* 36:524A, 1988.
11. McDonald, G.A., Molony, D.A., Reeves, W.B., and Andreoli, T.E.: Identification of Na<sup>+</sup>/K<sup>+</sup>/2Cl<sup>-</sup> cotransport activity in apical membrane vesicles of rabbit outer renal medulla. National Student Research Forum, Galveston, Spring 1988.
12. Mehta, P.S. and Molony, D.A.: Cl<sup>-</sup> flux in basolateral membrane vesicles (BMV) from rabbit renal medulla (RRM) is mediated via conductive and K<sup>+</sup>-dependent nonconductive mechanisms. *Kidney Int.* 35:485, 1989.
13. Molony, D.A. and Breyer, M.D.: Measurement of intracellular Cl<sup>-</sup> ([Cl<sup>-</sup>]<sub>i</sub>) in isolated perfused mouse medullary thick ascending limbs (mTAL) with the fluorescent dye 6-methoxyl-(3-sulfonatopropyl) quinolinium (SPQ). *Kidney Int.* 35: 485, 1989.

## Curriculum Vitae

Donald A. Molony, M.D.

14. Molony, D.A. and Breyer, M.D.: Antidiuretic hormone (ADH)/cAMP increase intracellular  $\text{Cl}^-$  ( $[\text{Cl}^-]_i$ ) in isolated perfused mouse medullary thick ascending limbs (mTAL). XXXI Inter. Cong. Physiol. Sci., Helsinki, Finland, 1989.
15. Molony, D.A. and Mehta, P.S.: cAMP dependent protein kinase (cAMP-PK) stimulates directly conductive  $\text{Cl}^-$  efflux from basolateral membrane vesicles (BMV) of the rabbit medullary thick ascending limb (mTAL). *Kidney Int.* 37:567, 1990.
16. Faillace, J. and Molony, D.A.: Calcium stimulates conductive  $\text{Cl}^-$  flux from basolateral membrane vesicles (BMV) of the rabbit medullary thick ascending limb (mTAL). (Presented at the National Student Research Forum, April, 1990).
17. Molony, D.A., Faillace, J. and Mehta, P.S.: Calcium stimulated conductive  $\text{Cl}^-$  flux from basolateral membrane vesicles (BMV) of the rabbit medullary thick ascending limb (mTAL) is not mediated by protein kinase C (PKC). *J. Am. Society of Nephrology* 1:689, 1990.
18. Mehta, P.S. and Molony, D.A.: Dieldrin (D) pesticides impair medullary thick ascending limb (mTAL) function via inhibition of the basolateral cell membrane  $\text{Cl}^-$  conductance. *J. Am. Society of Nephrology* 1:614, 1990.
19. Molony, D.A. and Mehta, P.S.: Calcium stimulates directly  $\text{Cl}^-$  flux from basolateral membrane vesicles (BMV) of the rabbit medullary thick ascending limb (mTAL). (Presenting Abstract at Am. Fed. Clin. Res., May, 1991).
20. Molony, D.A. and Mehta, P.S.: Hypotonic swelling stimulates KCl co-transport in basolateral membrane vesicles (BMV) from the rabbit medullary thick ascending limb (mTAL). American Society of Nephrology, Baltimore, Md, Nov. 1991.
21. Molony, D.A., Burges, A., Dubose, T., and Mehta, P.: Murine renal medullary  $\text{Cl}^-$  channels are similar in cDNA sequence to the  $\gamma$ -aminobutyric acid  $\alpha_1$   $\text{Cl}^-$  channel in the central nervous system. *Experimental Biology* 93, New Orleans, 1993.
22. Mehta, P.S., Hayes, B.E., and Molony, D.A.: Dieldrin pesticides impair medullary thick ascending limb basolateral cell membrane  $\text{Cl}^-$  conductance and produce distal nephron injury. *Experimental Biology* 93, New Orleans, 1993.
23. Molony, D.A. and Mehta, P.S.: Amplification by the polymerase chain reaction of DNA for a  $\text{Cl}^-$  channel as a urinary biomarker distal nephron injury due to pesticides. American Federation

## Curriculum Vitae

Donald A. Molony, M.D.

of Clinical Research, Washington, D.C. 1993.

24. Molony, D.A., Pressley, T., DuBose, T.D., and Mehta, P.: Murine renal medulla expresses a  $\gamma$ -aminobutyric acid (GABA)-A  $\alpha_1$  Cl<sup>-</sup> channel that differs in cDNA sequence from the central nervous system (CNS) channel. American Society of Nephrology, Boston, Nov. 1993.
25. Molony, D., Hamilton, R., Holian, A., and Mehta, P.S.: Renal localization of mRNA for a murine  $\tau$ -Aminobutyric Acid (GABA)<sub>A</sub>  $\alpha_1$  Cl<sup>-</sup> channel and increased expression after *in vivo* pesticide exposure. American Society of Nephrology, Nov. 1994.
26. Gitomer, J., Mehta, P.S., Molony, D.A.: Increased expression by *in situ* hybridization of a  $\gamma$ -aminobutyric acid (GABA) Cl<sup>-</sup> channel in cells in the urinary sediment from nephrotoxicant exposed mice. Clinical Research Meeting, May 1995.
27. Molony DA, Mehta, P, Hamilton,R., Holian, A.: Chronic *in vivo* exposure to the pesticides Dieldrin (D) and Lindane (L) induces apoptosis in the cells of the mouse mTAL. Am. Soc. Nephrol., New Orleans, Nov 1996.
28. Molony, DA, Kone, B., Holian, A., Mehta, P.: Inhibitors of cysteine protease interleukin-1 $\beta$ -converting enzyme (ICE) abolish the apoptosis of ST-1 cells induced by nephrotoxicant pesticides. Am. Soc. Nephrol., New Orleans, Nov 1996.
29. Molony, DA, Mehta, P.: Amlodipine (A) abolishes the apoptosis of ST-1 cells induced by nephrotoxicant pesticides. Am. Soc. Nephrol., New Orleans, Nov 1996.
30. Molony, DA, Patel, A., Mehta, P.: N-Acetyl-L-cysteine abolishes apoptosis in ST-1 cells induced by nephrotoxicant pesticides. Am. Soc. Nephrol. San Antonio, Nov. 1997
31. Molony, DA, Mehta, P., Gong, L., Kone, B., and Yeh, ETH: Apoptosis of murine medullary thick ascending limb cells in response to a nephrotoxicant; initiating and modulating events. Am. Soc. Nephrol. San Antonio, Nov. 1997.
32. Molony, DA, Mehta, P, Smith, MA: Pesticide induced apoptosis of murine medullary thick ascending limb cells in culture is inhibited by Cl<sup>-</sup> channel agonists. Society of Toxicology, Seattle, March, 1998.
33. Molony D, Moyer V, Ribble J: Incorporating EBM into Problem Based Learning. Northeast Group on Educational Affairs, 1998 Regional Meeting, April, 1998.

## Curriculum Vitae

Donald A. Molony, M.D.

34. Molony DA, Mehta P: Apoptosis of murine medullary thick ascending limb (mTAL) cells (ST-1) is initiated by pesticides and inhibited by GABA<sub>A</sub> Cl<sup>-</sup> channel agonists. *JASN* 9: 597A, 1998.
35. Castriotta RJ, Gokcebay N, Figueroa J, Atanga MB, Molony D: Sleep disturbance in chronic renal disease. *Chest* 114: 4S, 382, 1998.
36. Castriotta RJ, Figueroa J, Atanga MB, Gokcebay N, Mir F, Molony D: Sleep disturbance in chronic renal disease. *Sleep* 22: S314, 1999.
37. Molony DA, Knight D, Alexander PJ: Chronic pesticide exposure is associated with renal failure. *Am Soc Nephrology*, Miami, 1999.
38. Molony DA, Moyer V, Ribble J, Perkowski L, Rosenfeld G, Schultz S: Incorporating evidence-based-medicine into a pre-clinical problem-based-learning curriculum. *Advances in Teaching and Learning*, Houston March 2000.
39. Molony DA, Moyer V, Mayfield J, Colletti L, Farnie M: Problem-based-learning on a clinical service; An approach to cooperative student centered instruction. *Advances in Teaching and Learning*, Houston March 2000.
40. Molony DA, Brown WW, King K, Gannon M: Screening of high risk populations identifies a high prevalence of individuals with abnormal renal function: The NKF Kidney Early Evaluation Program. *Am Soc Nephrology*, Toronto, Can Oct 2000.
41. Molony DA, Bercu J, Smith MA: Apoptosis is increased in murine medullary thick ascending limb cells (ST-1) but inhibited in MDCK cells by Cl<sup>-</sup> channel agonists. *Am Soc. Nephrology / International Soc Nephrol*, San Francisco Ca, Oct 2001
42. Gaitanaru, D., Obeid, J., Figueroa, J., Clark, C., Molony, D. and Castriotta, R.J. Characterization of sleep disorders in end-stage renal disease patients undergoing hemodialysis. *Chest* 120:302S, 2001
43. Molony DA, Moyer V: Strategies for incorporating evidence-based-medicine into a pre-clinical problem-based-learning curriculum. *Advances in Teaching and Learning*, Houston March 2001.
44. Molony DA, Butler P, Perkowski L: A novel approach to student evaluation developed to foster the educational objectives of problem-based-learning. *Advances in Teaching and Learning*,

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

Houston March 2001.

45. Donald A Molony DA, Mayorga-Wark O: Apoptosis of murine medullary thick ascending limb (mTAL) (ST-1) but not MDCK cells is stimulated by antagonists and inhibited by agonists to GABA<sub>A</sub>  $\alpha 1$  Cl<sup>-</sup> channels. Am Soc Nephrol Philadelphia, Pa, Oct 2002.
46. Stack AG, Murthy BVR, Molony DA, Rahman SN, Dosekun A: Body mass index and mortality risk among new ESRD patients in the United States. National Kidney Foundation Scientific Meeting, Dallas, April 2003.
47. Stack AG, Murthy BVR, Molony DA, Rahman SN, Dosekun A: Association of higher body mass index with poorer survival among new ESRD patients treated with peritoneal dialysis in the United States. National Kidney Foundation Scientific Meeting, Dallas, April 2003.
48. Stack AG, Molony DA, Tyson J, Rivers T, Lasky R, Murthy BVR: Mortality differences by treatment modality among new ESRD patients with and without congestive heart failure in the United States. National Kidney Foundation Scientific Meeting, Dallas, April 2003.
49. Molony DA, Mayorga-Wark O, Jain D Demonstration of a GABA-Regulated Chloride Conductance in Mouse mTAL ST-1 Cells; A Potential Target for Toxicant-induced Apoptosis. Accepted for presented, American Soc Nephrology Annual Meeting, San Diego, 2003.

**Manuscripts:**

1. Friedman, W.F., Molony, D.A. and Kirkpatrick, S.E.: Prostaglandins: Physiological and Clinical Correlations. Advances in Pediatrics. 25:151-204, 1978.
2. Molony, D.A., Reeves, W.B., Hebert, S.C. and Andreoli, T.E.: ADH increases apical Na<sup>+</sup>:K<sup>+</sup>:2 Cl<sup>-</sup> entry in mouse medullary thick ascending limbs of Henle. Amer. J. Physiol. 252: F177-F187, 1987.
3. Hebert, S.C., Reeves, W.B., Molony, D.A., and Andreoli, T.E.: The medullary thick limb: Function and modulation of the single-effect multiplier. Kidney Internl. 31: 580-588, 1987.
4. Molony, D.A., Reeves, W.B., and Andreoli, T.E.: Some transport characteristics of mammalian renal diluting segments. Min. Elect. Metab. 13: 442-450, 1987.

## Curriculum Vitae

Donald A. Molony, M.D.

5. Molony, D.A., Reeves, W.B., and Andreoli, T.E.: Regulation of electrolyte transport processes in the medullary thick ascending limb. Proceedings of the Xth International Congress of Nephrology, 1987.
6. Molony, D.A. and Andreoli, T.E.: Diluting power of isolated thick ascending limbs of Henle. I. Peritubular hypertonicity blocks basolateral Cl<sup>-</sup> channels. Am. J. Physiol., 24: F1128 - F1137, 1988.
7. Reeves, W.B., Molony, D.A. and Andreoli, T.E.: Diluting power of isolated thick ascending limbs of Henle. III. Modulation of in vitro diluting power. Am. J. Physiol., 24: F1145 - F1154, 1988.
8. Reeves, W.B. and Molony, D.A.: The physiology of loop diuretic action. Seminars in Nephrology, VII:225, 1988.
9. Molony, D.A. and Reeves, W.B. and Andreoli, T.E.: Na<sup>+</sup>:K<sup>+</sup>: 2 Cl<sup>-</sup> Co-transport and the thick ascending limb. Kidney Internl. 36: 418-426, 1989.
10. Stockand, J., Sultan, A., Molony, D.A., DuBose, T., and Sansom, S.: Interactions of heavy metals with K channels of vascular smooth muscle. J. Toxic. Appl. Pharm. 121: 30 - 35, 1993.
11. Lisk, D.R., Grotta, J.C., Lamki, L.M., Tran, H.D., Taylor, J.W., Molony, D.A., Barron, B.J.: Should hypertension be treated after acute stroke? A randomized controlled trial using SPECT. Arch. Neurol. 50: 855 - 862, 1993.
12. DuBose, T.D., Molony, D.A., Verani, R., G. McDonald: Nephrotoxicity of non-steroidal anti-inflammatory drugs. Lancet Grand Rounds, Lancet 344: 515-518, 1994.
13. Wall, S.M., Johansen, M.J., Molony, D.A., DuBose, T.D., Jaffe, N., Madden, T.: Effective clearance of methotrexate using high flux hemodialysis membranes. Am. J. Kidney Dis. 28: 846-854, 1996.
14. National Kidney Foundation Report on Dialyzer Reuse: Task Force on Dialyzer Reuse, Council on Dialysis, National Kidney Foundation (Cheung, A; Golpers, TA; Ing, TS; Lang, GR; Lazarus, JM; Letteri, JM; Levin, NW; Lundin, PA; Molony, DA; Mujais, SK; Port, FK; and Ward, RA) National Kidney Foundation Report on Dialyzer Reuse; Am. J. Kid. Dis 30: 859 - 871, 1997.

## Curriculum Vitae

Donald A. Molony, M.D.

15. Brown WW, Collins A, Chen S-C, King K, Molony D, Gannon MR, Politoski G, Keane WF: Identification of persons at high risk for kidney disease via targeted screening: The NKF Kidney Early Evaluation Program. *Kidney Inter* 63: S50 -55, 2003.
16. Brown WW, Peters RM, Ohmit SE, Keane WF, Collins A, Chen S-C, King K, Klag MJ, Molony DA, Flack JM: Early detection of kidney disease in community settings: The Kidney Early Evaluation program. *Am J Kidney Dis* 42: 22 – 35, 2003.
17. Stack AG, Molony DA, Rahman N, Dosekun A, Murthy BVR: Impact of dialysis modality on survival of new ESRD patients with congestive heart failure in the United States. *Kidney Internal*. 64: 1071 -9, 2003.
18. Samuels JA, Strippoli GFM, Craig JC, Schena FP, Molony DA: Immunosuppressive and cytotoxic agents for treating IgA nephropathy [protocol]. *The Cochrane Library*, Issue 1, 2003.
19. Samuels JA, Strippoli GFM, Craig JC, Schena FP, Molony DA: Non-immunosuppressive treatment for IgA nephropathy [protocol]. *The Cochrane Library*, Issue 1, 2003.
19. Stack AG, Murthy BVR, Molony DA: Survival differences between peritoneal dialysis and hemodialysis among “large” ESRD patients in the United States. *Kidney International* 65: 2398 – 2408, 2004.
20. Murthy BVR, Molony DA, Stack AG: Differential survival among Hispanic and non-Hispanic subgroups initiating renal replacement therapy in the United States, Accepted *JASN* 2004.

## Book Chapters

1. Molony, D.A., and Jacobson, H.R.: Respiratory Disorders; Alkalosis and Acidosis. In: Differential Diagnosis and Management of Fluid, Electrolyte and Acid-Base Disorders, edited by Kokko, J.P., and Tannen, R.L., W. B. Saunders, 1986.
2. Molony, D.A., and Andreoli, T.E.: General Principles of Renal Tubular Transport. In: Textbook of Nephrology, Second Edition edited by Massry, S.G. and Glassock, R.J. Publishers Williams and Wilkins, Baltimore, 1988.
3. Molony, D.A., Schiess, M.C., and Evanoff, G.V.: Respiratory Disorders; Alkalosis and Acidosis. In: Differential Diagnosis and Management of Fluid, Electrolyte and Acid-Base

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

Disorders, edited by Kokko, J.P., and Tannen, R.L., Second Edition, W. B. Saunders, Philadelphia, 1990.

4. Eigenbrodt, E.H., Molony, D., DuBose, T.E.: Renal Involvement in Hepatic Disease, Rheumatoid Arthritis, Sjogren's Syndrome, and Mixed Connective Tissue Disease. In: The Pathology of Kidney Diseases (second edition), edited by Tisher, C and Brenner, B, 1993.
5. Molony, D.A., Schiess, M.C., and Dosekan, A.: Respiratory Disorders; Alkalosis and Acidosis. In: Differential Diagnosis and Management of Fluid, Electrolyte and Acid-Base Disorders, edited by Kokko, J.P., and Tannen, R.L., Third Edition, W. B. Saunders, Philadelphia, 1996.
6. Murthy BVR, Molony DA: Reprocessing of hemodialyzers. Chapter 19 in: Chronic Kidney Disease, Dialysis, and Transplantation (second edition) edited by Pereira BJJ, Sayegh M, and Blake P, Elsevier, Burlington MA 2004.

**Published Electronically:**

1. Molony D, Finkel K: Continuing Medical Education Exercise, January. Am. J. Kidney Dis. 31 (1): E2, 1998.
2. Molony D, Finkel K: Continuing Medical Education Exercise, February. Am. J. Kidney Dis. 31 (2): E2, 1998.
3. Molony D, Finkel K: Continuing Medical Education Exercise, March. Am. J. Kidney Dis. 31 (3): E2, 1998.
4. Molony D, Finkel K: Continuing Medical Education Exercise, April. Am. J. Kidney Dis. 31 (4): E2, 1998.
5. Molony D, Finkel K: Continuing Medical Education Exercise, May. Am. J. Kidney Dis. 31 (5): E2, 1998.
6. Molony D, Finkel K: Continuing Medical Education Exercise, June. Am. J. Kidney Dis. 31 (6): E2, 1998.

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

7. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, July. Am. J. Kidney Dis. 32 (1): E2, 1998.
8. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, August. Am. J. Kidney Dis. 32 (2): E2, 1998.
9. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, September. Am. J. Kidney Dis. 32 (3): E2, 1998.
10. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, October. Am. J. Kidney Dis. 32 (4): E2, 1998.
11. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, November. Am. J. Kidney Dis. 32 (5): E2, 1998.
12. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, December. Am. J. Kidney Dis. 32 (6): E2, 1998.
13. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, January. Am. J. Kidney Dis. 33 (1): E2, 1999.
14. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, January. Am. J. Kidney Dis. 33 (2): E2, 1999.
15. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, March. Am. J. Kidney Dis. 33 (3): E2, 1999.
16. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, April. Am. J. Kidney Dis. 33 (4): E2, 1999.
17. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, May. Am. J. Kidney Dis. 33 (5): E2, 1999.
18. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, June. Am. J. Kidney Dis. 33 (6): E2, 1999.
19. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, July. Am. J. Kidney Dis. 34 (1): E2, 1999.

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

20. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, August. Am. J. Kidney Dis. 34 (2): E2, 1999.
21. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, September. Am. J. Kidney Dis. 34 (3): E2, 1999.
22. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, October. Am. J. Kidney Dis. 34 (4): E2, 1999.
23. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, November. Am. J. Kidney Dis. 34 (5): E2, 1999
24. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, December. Am. J. Kidney Dis. 34 (5): E2, 1999
25. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, January. Am. J. Kidney Dis. 35 (1): E2, 2000
26. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, February. Am. J. Kidney Dis. 35 (2): E2, 2000
27. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, March. Am. J. Kidney Dis. 35 (3): E2, 2000
28. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, April. Am. J. Kidney Dis. 35 (4): E2, 2000
29. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, May. Am. J. Kidney Dis. 35 (5): E2, 2000
30. Molony D, Finkel K, Gitomer J, Grimm E: Continuing Medical Education Exercise, June. Am. J. Kidney Dis. 35 (6): E2, 2000
31. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, July. Am. J. Kidney Dis. 36 (1): E2, 2000
32. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, August. Am. J.

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

- Kidney Dis. 36 (2): E4, 2000
33. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, September. Am. J. Kidney Dis. 36 (3): E14, 2000
  34. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, October. Am. J. Kidney Dis. 36 (4): E23, 2000
  35. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, November. Am. J. Kidney Dis. 36 (5): E29, 2000.
  36. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, December. Am. J. Kidney Dis. 36 (6): E31, 2000.
  37. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, January. Am. J. Kidney Dis. 37 (1): E2, 2001.
  38. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, February. Am. J. Kidney Dis. 37 (2): E4, 2001.
  39. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, March. Am. J. Kidney Dis. 37 (3): E14, 2001.
  40. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, April. Am. J. Kidney Dis. 37 (4): E23, 2001.
  50. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, May. Am. J. Kidney Dis. 37 (5): E29, 2001.
  51. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, June. Am. J. Kidney Dis. 37 (6): E2, 2001.
  52. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, July. Am. J. Kidney Dis. 38 (1): E2, 2001.
  53. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, August. Am. J. Kidney Dis. 38 (2): E4, 2001.

## **Curriculum Vitae**

**Donald A. Molony, M.D.**

54. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, September, Am. J. Kidney Dis. 38 (3): E14, 2001.
55. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, October. Am. J. Kidney Dis. 38 (4): E23, 2001.
56. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, November. Am. J. Kidney Dis. 38 (5): E29, 2001.
57. Molony D, Finkel K, Gitomer J: Continuing Medical Education Exercise, December. Am. J. Kidney Dis. 38 (6): E2, 2001.

### **Educational Materials (National Organizations)**

1. Brouwer D, Givens A, McCann L, Moe SM, Molony DA: Getting to Goal; A Multidisciplinary Approach to Phosphorus Management. National Kidney Foundation-Kidney Learning System 2004
2. Moe SM, Klemmer P, Molony DA, McCann L: The Well-Controlled Patient: Looking beyond the lab tests. The National Kidney Foundation 2004.

### **Educational Materials – Developed for use at UT-Houston:**

1. Molony, D.A. and the Principles Working Group; "PBL Case: Sandra Henry; A 23-year-old woman brought to the emergency room with loss of consciousness, nausea, and vomiting." 1994, revised 1995, 1996, 1999, 2000.
2. Smallling, R. and Molony, D.A. and the Cardiovascular Working Group; "PBL case: Mr. Cook: A case of a 52-year-old man presenting with chest pain." 1994, revised 1995, 1996.
3. Smallling, R., and Molony, D.A. and the Cardiovascular Working Group; "PBL case: Mrs. Schwarz." 1994, revised 1995, 1996.
4. Molony, D.A. and members of the Renovascular Working Group; "PBL case: Mr. Green: Case of a 55-year-old African-American man with newly diagnosed high blood pressure." 1994, revised 1995.

## **Curriculum Vitae**

**Donald A. Molony, M.D.**

5. Molony, D.A. and members of the Renovascular Working Group; "PBL case: Mrs. Brown: Mary Brown is concerned about her ankle swelling." 1994, revised 1995.
6. Molony, D.A. and Finkel, K and members of the Renovascular Working Group; "PBL case: Mrs. Brown: Mary Brown is concerned about her ankle swelling." 1996 revision.
7. Molony, DA and members of the renovascular working group; "PBL case: Vergie Lillie," 1999, revised 2002.
8. Molony, D.A. and members of the Renovascular Working Group; "PBL case: Dennis Vincent: A 35-year-old African-American man with high blood pressure." 1996.
9. Molony, DA: "Renal failure: A multicultural perspective." Family Focus: A Newspaper for patients and their families; National Kidney Foundation, Inc., New York, NY. Vol 7: 6. 1997.
10. FCM Syllabus: Editor: produced yearly 1991 to 2003
11. FCM / PBL Examinations (7 per year 1991 – 1997, 5 per year 1997 - present): 1991 to 2003.
12. Molony DA and Orlander P; PBL case: Albert Bright: 17 year-old with hereditary nephritis and renal failure, 2000, revised 2002.
13. Molony DA: PBL case of Anges Cooper: 82 year-old woman with aortic stenosis and diastolic dysfunction, 2002.

### **Invited Lectures:**

(1996 - 2001)

1. Medical Grand Rounds: Maricopa County Hospital, Phoenix Ar. Toxic nephropathy. May 1996.
2. Renal Grand Rounds: Vanderbilt University, School of Medicine, Nashville, Tn. Toxic and analgesic nephropathy, a subtle cause of chronic renal failure, Nov. 1996
3. Renal Research Conference: Vanderbilt University, School of Medicine, Nashville, Tn Nov. 1996.
4. Quarterly Meeting of the National Kidney Foundation of New England: Early Intervention and Prevention of Renal Disease, March 1996.

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

5. Grand Rounds: Department of Family Practice: Pathogenesis and Treatment of Acute Renal Failure, April 3, 1996.
6. Internal Medicine Faculty Research Conference: Cellular Mechanisms of Nephrotoxicant Pesticides. May 13, 1997
7. Annual Meeting of the National Kidney Foundation: Patient Services Symposium: "Early Recognition and Prevention of Renal Disease, Indiana Project," New Orleans, Nov, 1996.
8. National Kidney Foundation; "Symposium for Pilot Project of the KEEP Program" New York, Feb. 8 & 9, 1997.
9. Lupus Foundation of Southeast Texas, Annual Patient Symposium. "Lupus and Renal Disease." 1996, 1997, 1999.
10. Turner Syndrome Society; Annual Meeting: "Renal effects of Turner Syndrome." San Antonio, Tx, Nov 16, 1996.
11. Cardiology Division - Grand Rounds: Hypertension, Feb, 1997.
12. Department of Pediatrics: Grand Rounds: Recognition of toxic nephropathies in children. 6/97.
13. Medical Grand Rounds: South Georgia Medical Center: Early Intervention to Prevent the Development of End-stage Renal Disease; June 3, 1997
14. Distance Learning Project at UT-Pan American University; July 1997.
15. Texas Academy of Family Practice - Annual Meeting: General Session; "Chronic renal failure, early recognition, and prevention of progression. Galveston, August 2, 1997.
16. Invited Faculty for the International Evidence Based Medicine Conference: McMaster University, June 13 - 20, 1997.
17. Medical Grand Rounds Memorial Northeast Medical Center, Sept 16, 1997.
18. End of Life Symposium - UTH Medical School; Panel participant.

## **Curriculum Vitae**

**Donald A. Molony, M.D.**

19. Summary Presentation: Kidney Early Evaluation Program, Spring Annual Meeting; Nashville, Tn, March 29, 1998.
20. Presentation of Results from the Kidney Early Evaluation Program; ? A successful strategy for early identification of individuals at risk for kidney failure.? Pfizer, Inc National Advisory Board, April 2, 1998.
21. Incorporating EBM into Problem Based Learning. Seminar at the Northeast Group on Educational Affairs, 1998 Regional Meeting, April, 1998.
22. Invited Faculty for the International Evidence Based Medicine Conference: McMaster University, June 14 - 19, 1998.
23. Invited Faculty for the International Evidence Based Medicine Conference: McMaster University, June 19 - 24, 1999.
24. Visiting Professor: University of Hong Kong Medical School, Conducted seminar series and attended ward rounds on: "How to bring problem-based learning to the wards." July 12 - 16, 1999.
25. Co-moderator for: "Novel markers and mechanisms of renal damage in glomerular disease," free communications session, Am Soc Nephrology 1999 Annual Meeting, Miami Beach, 1999.
26. Annual Meeting of the National Kidney Foundation: Volunteer and patient symposium: Advances in renal research; implications for the development of new therapies, Miami, 1999.
27. Visiting Professor: University of Hong Kong: How to bring PBL to the wards: Faculty development. April 4 - 9, 2000.
28. Invited Faculty for the International Evidence Based Medicine Conference: McMaster University, June 12 - 16, 2000.
29. Annual Meeting of the Gulf Coast Society of Enteral and Parenteral Nutrition: Sustained low efficiency Dialysis. April 2001.
30. Renal Grand Rounds: University of Texas Houston Medical School: Progressive renal failure in special populations. Sept 2001

**Curriculum Vitae**  
**Donald A. Molony, M.D.**

31. Renal Grand Rounds: University of Texas Houston Medical School: IgA Nephropathy: An Evidence Based Approach, October 2001.
32. Renal Grand Rounds; Baylor College of Medicine: Environmental and Occupational Kidney Diseases; New insights from the clinic and laboratory. October 14, 2001
33. Grand Rounds; Medical Specialties MD Anderson Cancer Center 2002
34. Renal Research Conference; Baylor College of Medicine 2002
35. Grand Rounds: Department of Cardiovascular Surgery, Renovascular Hypertension 2/2003
36. Invited Faculty for the International Evidence Based Medicine Conference: McMaster University, June 22 - 27, 2003.

**EXHIBIT B**

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25

STATE OF NEW MEXICO  
WATER QUALITY CONTROL COMMISSION

IN THE MATTER OF  
PROPOSED AMENDMENTS TO AMEND  
20.6.2 NMAC - WATER QUALITY  
REGULATIONS

TRANSCRIPT OF PROCEEDINGS

BE IT REMEMBERED that on the 22nd day of  
September, 2003, the above-entitled matter came on for  
hearing before the New Mexico Water Quality Control  
Commission, taken at the State Capitol Building, Room  
321, and the Harold Runnels Building Auditorium, Santa  
Fe, New Mexico, at the hour of 9:00 AM.

VOLUME 1



## 1                   A P P E A R A N C E S (Continued)

2   For the New Mexico Mining Association:

3           COMEAU, MALDEGEN, TEMPLEMAN & INDALL, LLP  
4           Attorneys at Law  
5           141 East Palace Avenue  
6           Post Office Box 669  
7           Santa Fe, New Mexico 87504-

0669

By:   STEPHEN J. LAUER  
          JON J. INDALL7           GALLAGHER & KENNEDY, PA  
8           Attorneys at Law  
9           2575 East Camelback

Road

Phoenix, Arizona  
85016 9 By:   LYLE RIGGS10   For the University of California Board of  
Regents:11           MONTGOMERY & ANDREWS, PA  
12           Attorneys at Law  
13           325 Paseo de Peralta  
14           Post Office Box 2307  
15           Santa Fe, New Mexico 87504-2307  
16           By:   LOUIS W. ROSE15   For the New Mexico Department of  
Health:16           CLIFFORD M. REES  
17           Assistant General Counsel  
18           Office of General Counsel  
19           New Mexico Department of Health 18  
20           Santa Fe, New Mexico 87501

1190 St. Francis

Drive

19

20

21

22

23

24

25

## I N D E X

	PAGE
1	
2	
3 WITNESSES:	
4 DENNIS MC QUILLAN	
5     Direct Examination by Mr. Noble	32
6 STEPHEN WUST, PhD	
7     Direct Testimony	88
8     Cross Examination by Mr. Indall	96
9     Cross Examination by the Commission	98
10 STANLEY RASMUSSEN	
11     Direct Testimony	102
12     Cross Examination by the Commission	107
13 GALE HENSLEE	
14     Direct Testimony	109
15     Cross Examination by Mr. Noble	116
16     Cross Examination by the Commission	119
17 JOHNNYE L. LEWIS, PhD	
18     Direct Examination by Mr. Dolan	121
19 DONALD A. MOLONY, MD	
20     Direct Examination by Mr. Noble	235
21	
22	
23	
24	
25	

1

DONALD A. MOLONY, MD

2

having been first duly sworn or affirmed, was

3

examined and testified as follows:

4

## DIRECT EXAMINATION

5

BY MR. NOBLE:

6

Q. Will you please state your name for the

7

record?

8

A. My name is Dr. Donald A. Molony, MD, from

9

Houston, Texas.

10

Q. Dr. Molony, would you please describe your

11

educational background and relevant work experience?

12

A. I completed my undergraduate education in

13

biology with a degree in experimental biology with

14

honors from Yale University in 1974 and then proceeded

15

to the University of California San Diego Medical

16

School, where I received the degree of Doctor of

17

Medicine in 1978.

18

I then continued training at the University of

19

Texas Southwestern Medical School in Dallas under the

20

direction of Dr. Donald Seldin in internal medicine and

21

then a three-year fellowship in nephrology, or kidney

22

diseases, under the direction of Dr. Juha Kokko and

23

Dr. Harry Jacobson.

24

Dr. Jacobson's laboratory was a lab that I

25

spent two years in postdoctoral research training,

1 completing some preliminary work on the transport  
2 properties of the proximal tubule and the cortical  
3 collecting tubule, which are nephron segments that we  
4 may talk a bit more about today, particularly the  
5 proximal tubule.

6           After completing that fellowship, I joined as  
7 a faculty member the laboratory and the division under  
8 the direction of Dr. Thomas Andreoli.

9           Dr. Andreoli, parenthetically, is currently  
10 the Chairman of Medicine at the University of Arkansas  
11 School of Medicine, Dr. Kokko is the ex-Chairman of the  
12 Department of Medicine at Emory, and Dr. Harry Jacobson  
13 is the Vice-Chancellor for Health Sciences at  
14 Vanderbilt, all of whom have mentored me in my early  
15 career.

16           Under Dr. Andreoli, we pursued investigative  
17 interest -- I pursued an investigative interest in the  
18 function of the thick ascending limb, which is the  
19 nephron segment that essentially follows -- the  
20 principal nephron segment that follows the proximal  
21 tubule.

22           And in investigating the basic transport  
23 properties of the thick ascending limb, I discovered  
24 that these were affected by a number of environmental  
25 agencies' acts.

1           And so for the last 10 or so years, I have  
2 pursued investigative work on the toxic injury,  
3 principally to the thick ascending limb from  
4 environmental toxicants, first under direct support from  
5 the Environmental Protection Agency for five years of  
6 investigative support, and now I'm with the current  
7 National Institutes of Health - NIEHS RO1 grant, which  
8 is supporting work in this area.

9           As part of this investigation, I discovered  
10 that it was important to understand how the studies that  
11 I was conducting in the three specialties of interest to  
12 us today in our deliberations here, that is mice, rat  
13 and rabbit -- how they -- I needed to determine how this  
14 disease or illness that I was identifying -- or injury  
15 that I was identifying might apply to human populations.

16           So I began to pursue some investigations of  
17 the risk to individuals on dialysis of exposures to the  
18 various environmental toxicants.

19           And so I've developed a series of biomarkers,  
20 utilizing a number of the biomarkers that we have  
21 discussed -- that Dr. Lewis has already discussed, in my  
22 laboratory to try to determine the site-specific nature  
23 of the injuries that we were identifying in both human  
24 and animal populations.

25           And we've developed a very specific biomarker

1 to differentiate proximal tubule from thick ascending  
2 limb injury in my laboratory.

3 In addition, I have spent some time over the  
4 last 10 years as investigating -- or participating in  
5 the development of principles of evidence-based  
6 medicine.

7 I have tutored as an educator in the  
8 Evidence-Based Medicine International Workshop out of  
9 McMaster University in Hamilton, Ontario, which is where  
10 EBM really was founded. And this is now a principle  
11 that is guiding medicine worldwide. And I've tutored  
12 there eight of the last 10 years.

13 In addition, I'm a member of our Center for  
14 Evidence-Based Medicine and Clinical Epidemiology, and  
15 actually, currently I'm directing a graduates course in  
16 evidence-based health care policy for a master's degree  
17 program in clinical study design.

18 Q. What are your current job duties?

19 A. In addition to the laboratory investigations  
20 that I have described, I am also the director of the  
21 fundamentals of clinical medicine course in our  
22 institution, which is a pathophysiology bridging course  
23 for the second-year students.

24 And I am director of problem-based learning at  
25 the University of Texas Houston Medical School.

1 I'm also an attending physician, a professor  
2 of internal medicine in the Division of Renal Diseases  
3 and Hypertension in the Department of Internal Medicine  
4 at the University of Texas Houston Medical School, as  
5 well as professor -- adjunct professor at the University  
6 of Texas MD Anderson Cancer Center and -- a joint  
7 appointment there, as well as in the Department of  
8 Physiology and the graduate school and School of Public  
9 Health.

10 I also co-direct the toxicology graduate  
11 program with a colleague in the School of Public Health,  
12 and I am medical director of a large dialysis unit in  
13 Houston, caring for over a hundred patients in a renal  
14 care group downtown.

15 So I have clinical responsibilities, teaching  
16 responsibilities, and I maintain an interest in both  
17 clinical and basic laboratory investigations.

18 Q. Are you a member of any boards or associations  
19 that are relevant to your testimony today?

20 A. I think the -- it's relevant to my testimony  
21 that I have been a participant or member of the national  
22 board of the National Kidney Foundation, and for a  
23 number of years, I headed the Patient Services Committee  
24 that -- of the national board of the National Kidney  
25 Foundation, as well as the Kidney Early Evaluation

240

1 Program, or KEEP, from the National Kidney Foundation,  
2 which was a screening program to try to identify  
3 individuals in the population at high risk.

4 In addition, I've just been appointed to the  
5 Medical Review Board for Network 14, the end stage renal  
6 disease program that covers the State of Texas. Network  
7 15 covers New Mexico, Colorado, Wyoming, Utah and -- my  
8 list here -- Nevada.

9 And so the nation is divided into a number of  
10 different networks, and these are charged by the CMS and  
11 the Departments of Health with overseeing care for  
12 dialysis patients nationally.

13 Q. Have you performed any editorial functions in  
14 the past?

15 A. I was -- between 1996 and 2002, I was an  
16 associate editor in charge of the section for continuing  
17 medical education for the American Journal of Kidney  
18 Disease, in which I reviewed every article submitted and  
19 published in the American Journal of Kidney Disease, and  
20 developed on the best evidence within that journal an  
21 educational piece every month for approximately six  
22 years.

23 In addition, I have peer-reviewed papers for  
24 the American Journal of Kidney Disease, the Kidney  
25 International, the Journal of Clinical Investigation,

**EXHIBIT C**

# Testimony

## September 2003

Donald A. Molony, M.D.  
Professor of Internal Medicine, Nephrology  
Division of Renal Diseases and Hypertension  
And  
Center for Evidence Based Medicine and Clinical Epidemiology  
Medical Director – Renal Care Group Downtown Dialysis Center  
Director of Problem-Based Learning  
University of Texas HSC Houston Medical School

Disclaimer: Various illustrations and examples in this document are adapted from copy protected materials and should not be used in any other context or for any other purpose and are for illustration of the arguments presented in this document only.

1

### Core Issue: How can low levels of chronic exposure to Uranium contribute to increased risk of kidney disease / loss of health in the community?

Uranium results in acute and chronic injury to the proximal tubule that is demonstrated by both changes in kidney function and structure. I will review:

- The overall health impact of chronic kidney disease including ESRD to provide a perspective for these considerations. I will note how traditional measures of kidney damage may not identify these individuals.
- The role of tubular and interstitial damage in progression to chronic kidney disease.
- The interplay between injury at the glomerulus and the tubule that results in an acceleration of kidney damage.
- The additional risk potential in more vulnerable populations where the risk is increased by virtue of other illnesses occurring concurrently and by virtue of residing in a dry warm environment.

2

## Distinguishing features of chronic kidney disease (CKD) in clinical practice

- Defined best as a reduction in glomerular filtration rate (GFR); also estimated by the net clearance of creatinine (CrCl). Normal is roughly 110 -120 ml/min
- Serum creatinine level (blood test) is easy to measure and the most commonly used index of kidney insufficiency / failure. Very useful in the most severely affected individuals. Normal up to 1.4 mg/dl in men and 1.2 mg/dl in women.
- Other commonly used clinical measures of kidney disease include evidence of abnormal protein type and quantity in the urine (proteinuria), hematuria (red cells in the urine).

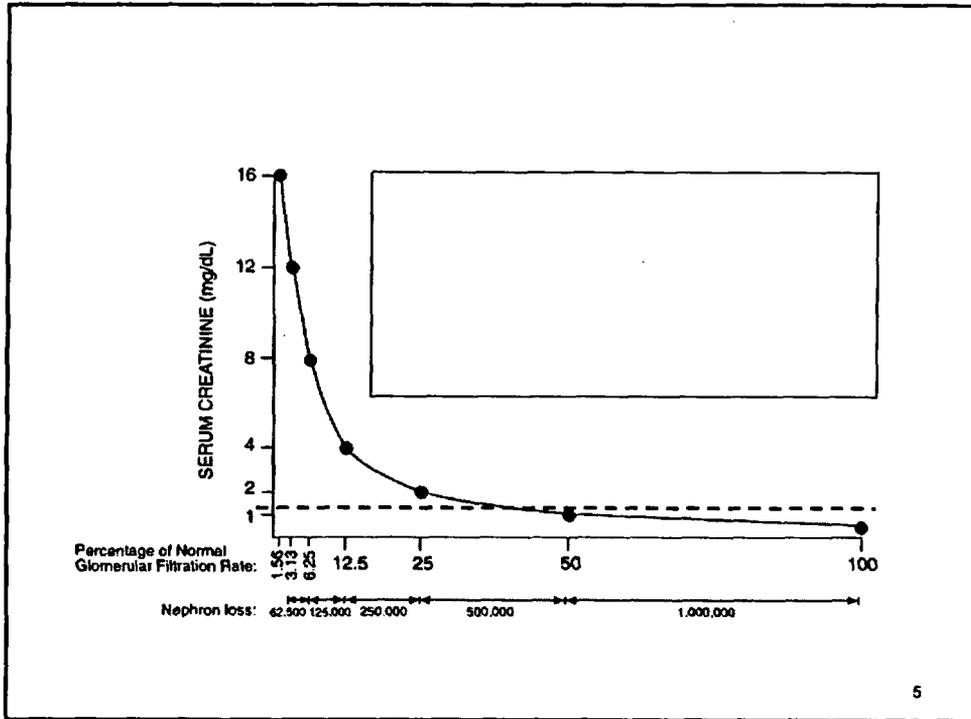
3

## Measures for defining CKD of stage III or higher

- Glomerular filtration rate (GFR)
  - Best indicator, usually estimated
  - Renal insufficiency  $\square$  70 mL/min/1.73 m<sup>2</sup>
- Serum creatinine (SCr)
  - Women  $\geq$ 1.5 mg/dL
  - Men  $\geq$ 2.0 mg/dL
  - Over 65 years old  $>$ 1.2 mg/dL
- Creatinine clearance (Ccr)  $<$ 70 mL/min

Di Piro. *Pharmacotherapy: A Pathophysiologic Approach*. Appleton and Lange; 1997.  
McCarthy. *Mayo Clin Proc*. 1999;74:269.

Consensus Development Conference Panel. *Ann Intern Med*. 1994;121:62.



5

Appendix Table 1. Serum Creatinine Corresponding to an Estimated Glomerular Filtration Rate of 60 mL/min per 1.73 m<sup>2</sup> by the Abbreviated Modification of Diet in Renal Disease Study and Cockcroft-Gault Equations\*

Age	Serum Creatinine Concentration					
	MDRD Study Equation				Cockcroft-Gault Equation	
	European-American		African-American		Men	Women
	Men	Women	Men	Women		
	← μmol/L (mg/dL) →					
30	130 (1.47)	100 (1.13)	153 (1.73)	118 (1.34)	162 (1.83)	138 (1.56)
40	123 (1.39)	95 (1.08)	146 (1.65)	112 (1.27)	148 (1.67)	126 (1.42)
50	118 (1.34)	91 (1.03)	140 (1.58)	108 (1.22)	133 (1.50)	113 (1.28)
60	115 (1.30)	88 (1.00)	135 (1.53)	104 (1.18)	118 (1.33)	100 (1.13)
70	111 (1.26)	86 (0.97)	132 (1.49)	102 (1.15)	103 (1.17)	88 (0.99)
80	109 (1.23)	84 (0.95)	129 (1.46)	99 (1.12)	88 (1.00)	75 (0.85)

\* Calculations in this table use serum creatinine values obtained in the MDRD study central laboratory, which were a mean of 0.23 mg/dL lower than duplicate samples analyzed at the Third National Health and Nutrition Examination Survey central laboratory. Calculations in this table assume a weight of 72 kg and body surface area of 1.73 m<sup>2</sup>. MDRD = Modification of Diet in Renal Disease. Reprinted with permission from reference 7.

6

## NKF-K/DOQI Staging Classification of CKD

Stage	Description	GFR
1	Chronic kidney damage with normal or ↑ GFR	> 90
2	Mild ↓ GFR	60–89*
3	Moderate ↓ GFR	30–59
4	Severe ↓ GFR	15–29
5	Kidney failure	<15 or dialysis

GFR: mL/min/1.73 m<sup>2</sup>

\*May be normal for age

Prepublished Staging Classification

**Table 4. National Kidney Foundation Kidney Disease Outcomes Quality Initiative Classification, Prevalence, and Action Plan for Stages of Chronic Kidney Disease\***

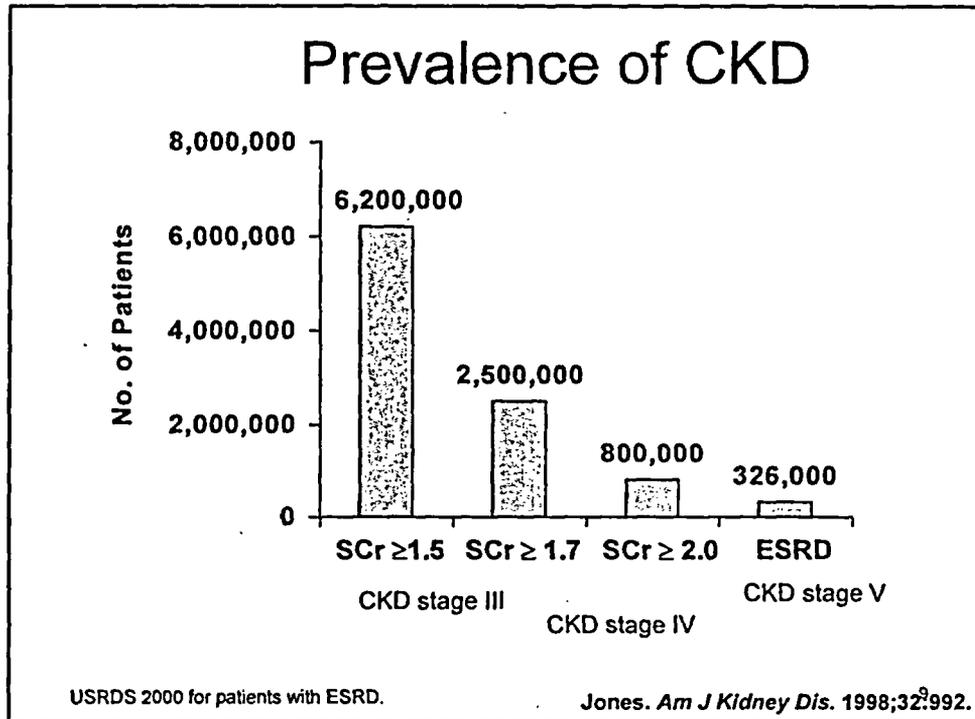
Stage†	Description	GFR, mL/min per 1.73 m <sup>2</sup>	Prevalence, n (%)‡	Action§
—	At increased risk	≥60 (with chronic kidney disease risk factors)	—	Screening; chronic kidney disease risk reduction
1	Kidney damage with normal or increased GFR	≥90	5 900 000 (3.3)	Diagnosis and treatment; treatment of comorbid conditions; slowing progression; CVD risk reduction
2	Kidney damage with mild decreased GFR	60–89	5 300 000 (3.0)	Estimating progression
3	Moderately decreased GFR	30–59	7 600 000 (4.3)	Evaluating and treating complications
4	Severely decreased GFR	15–29	400 000 (0.2)	Preparation for kidney replacement therapy
5	Kidney failure	<15 (or dialysis)	300 000 (0.1)	Kidney replacement (if uremia present)

\* CVD = cardiovascular disease; GFR = glomerular filtration rate. Modified and reprinted with permission from reference 7.

† Stages 1 to 5 indicate patients with chronic kidney disease; the row without a stage number indicates persons at increased risk for developing chronic kidney disease. Chronic kidney disease is defined as either kidney damage or GFR less than 60 mL/min per 1.73 m<sup>2</sup> for 3 or more months. Kidney damage is defined as pathologic abnormalities or markers of damage, including abnormalities in blood or urine tests or imaging studies.

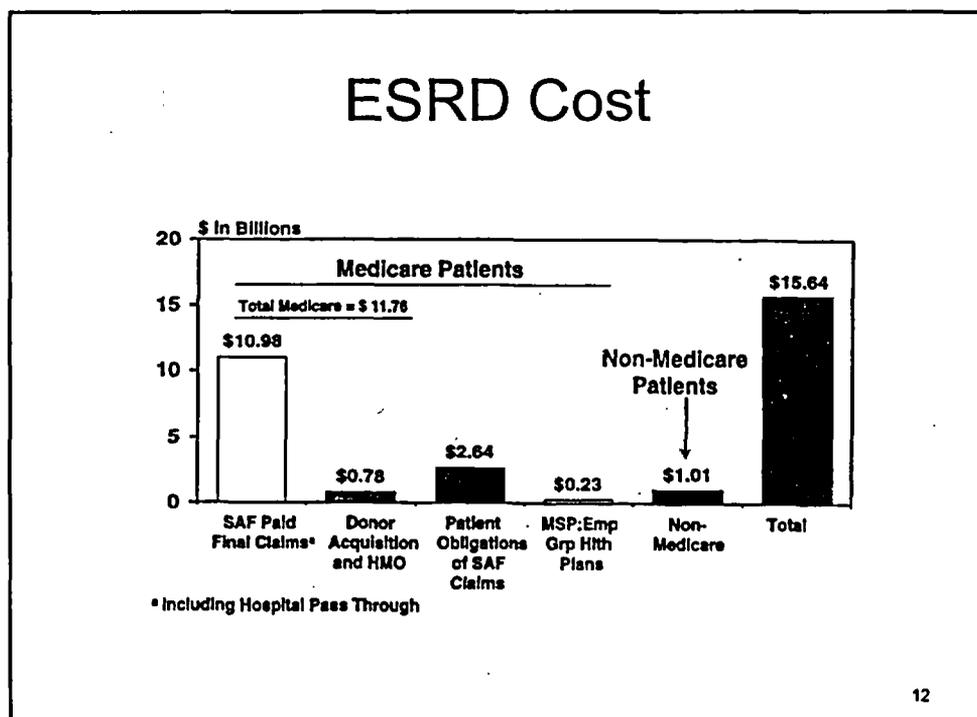
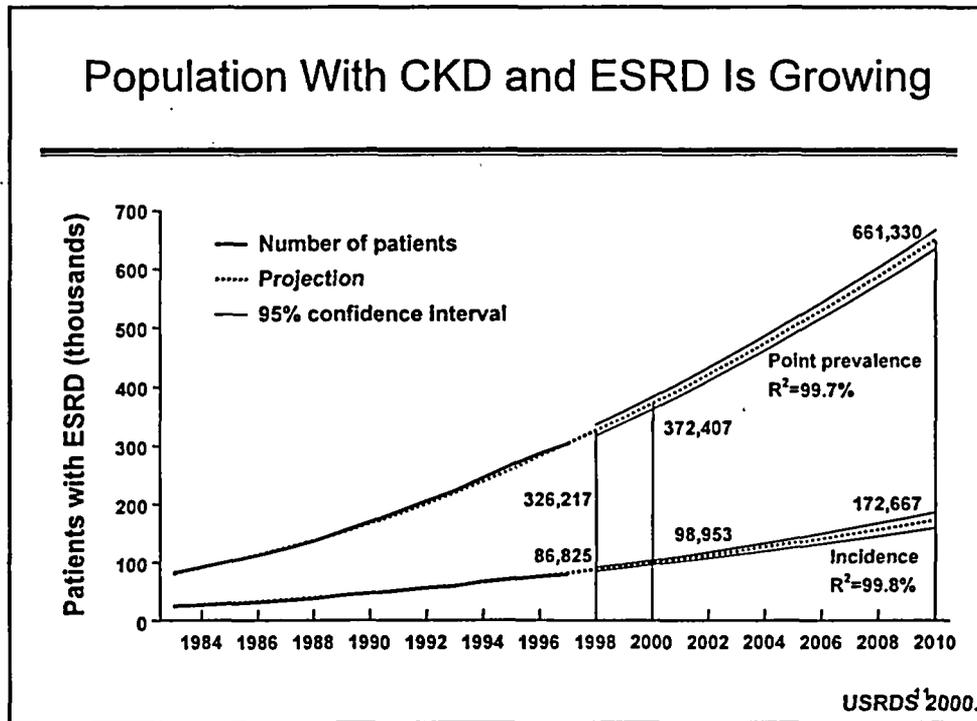
‡ Prevalence for stage 5 is from the U.S. Renal Data System (1998); it includes approximately 230 000 patients treated with dialysis and assumes 70 000 additional patients not receiving dialysis. Prevalence for stages 1 to 4 is from the Third National Health and Nutrition Examination Survey (1988 to 1994). Population of 177 million adults age 20 or more years. Glomerular filtration rate is estimated from serum creatinine measurements by using the Modification of Diet in Renal Disease study equation based on age, sex, race, and calibration for serum creatinine. For stages 1 and 2, kidney damage is estimated by using untimed urine samples to determine the albumin-creatinine ratios; greater than 17 mg/g in men or greater than 25 mg/g in women on two measurements indicates kidney damage. The proportion of persons at increased risk for chronic kidney disease has not been estimated accurately.

§ Includes actions from preceding stages.

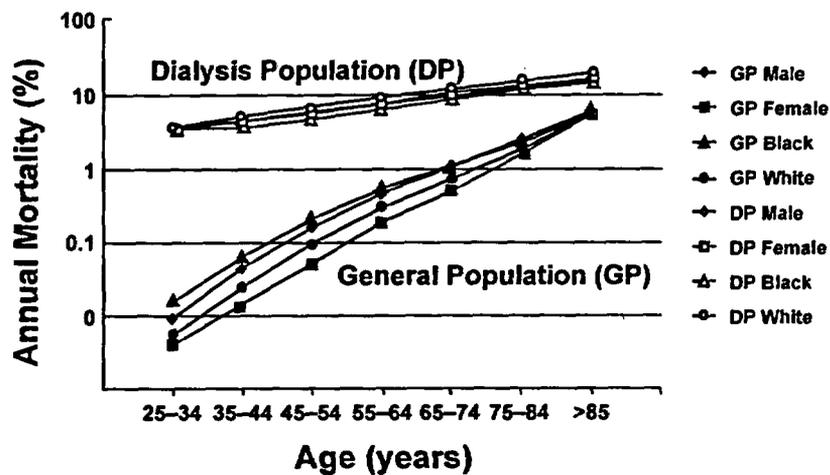


### Consequence of CKD:

- Increased risk of premature cardiovascular death (heart attack, stroke, congestive heart failure)
  - Risk at all levels of CKD, cardiovascular risk increases with stage or degree of CKD
    - CKD Stage II: Risk for premature CV death estimated as 1.5 – 2 x general population of similar age and co-morbidities
    - CKD III – VI: Risk increases to 4- 5 x in some observational studies
  - Stroke risk increased in individuals with CKD III or greater
- Increased severity of hypertension
- Increased degree of insulin resistance
- Increased prevalence of sleep apnea



## Cardiac and Cardiovascular Mortality



Sarnak. *Am J Kidney Dis.* 2000;35(suppl 1):S117.

## Incidence of ESRD in 1997

Table B-2. Treated Medicare ESRD Incidence Counts, Rates, and Average Rate Change by Age, Sex, Race, and Primary Diagnosis

Characteristic†	1997*			Average % Rate Change‡	
	Count (no.)	Percent of Total	Rate per Million‡	1988-1992	1992-1996
Age 0-19	1,069	1.4	13	2	4
Age 20-44	11,800	14.9	109	5	4
Age 45-64	28,253	33.2	545	8	6
Age 65-74	22,056	27.9	1296	11	5
Age 75+	17,824	22.7	1282	14	8
Female	36,873	46.7	242	10	5
Male	42,129	53.3	348	9	8
Asian/Pacific Islander	2,363	3.0	344	2	11
Black	22,826	29.0	873	10	6
Native American	928	1.2	586	13	8
White	51,171	64.7	218	9	5
Other/unknown	1,694	2.1	NA	NA	NA
Diabetes	33,096	41.8	120	14	9
Hypertension	20,066	25.4	73	11	1
Glomerulonephritis	7,390	9.3	27	3	3
Cystic kidney disease	1,772	2.2	8	4	1
Total	79,102	100.0	287	9	5

Abbreviation: NA, not available.

\*Data are preliminary for 1997.

†Patients from Puerto Rico or US territories are not included. Patients with other or unknown race are excluded from rate analyses. Other urologic, other, unknown, and missing cause of ESRD are included in the total but are not shown.

‡Rates are adjusted for age, sex and race. Rates are computed relative to the corresponding population for age, sex, and race results.

Source: Reference Table A.1 for the counts and A.6 for the rates.

## Prevalence of ESRD in 1997

542

USRDS 1999 ANNUAL DATA REPORT

**Table B-1. Treated Medicare ESRD Point Prevalence Counts, Rates, and Average Rate Change by Age, Sex, Race, and Primary Diagnosis**

Characteristic	1997			Average % Rate Change	
	Count (no.)	Percent of Total	Rate per Million†	1986-1992	1992-1996
Age 0-19	5,480	1.8	86	3	3
Age 20-44	78,018	25.0	708	6	4
Age 45-64	117,865	38.8	2,360	9	7
Age 65-74	63,197	20.8	3,840	12	8
Age 75+	41,523	13.7	3,027	15	10
Female	136,907	45.7	831	9	7
Male	165,176	54.3	1,314	9	7
Asian/Pacific Islander	10,795	3.6	1,369	6	9
Black	97,503	32.1	3,579	10	7
Native American	4,814	1.5	2,773	14	10
White	186,341	61.3	803	9	6
Other/unknown	4,830	1.6	NA	NA	NA
Diabetes	100,892	33.2	366	15	11
Hypertension	72,981	24.0	266	11	5
Glomerulonephritis	52,228	17.2	190	6	5
Cystic kidney disease	13,992	4.6	51	6	4
Total	304,063	100.0	1,105	9	7

Abbreviation: NA, not available.  
 †Data are preliminary for 1997.  
 ‡Patients from Puerto Rico or US territories are not included. Patients with other or unknown race are excluded from rate analyses. Other urologic, other, unknown, and missing cause of ESRD are included in the total but are not shown.  
 §Rates are adjusted for age, sex and race. Rates are computed relative to the corresponding population for age, sex, and race results.  
 Source: Reference Table B.1 for the counts and B.8 for the rates.

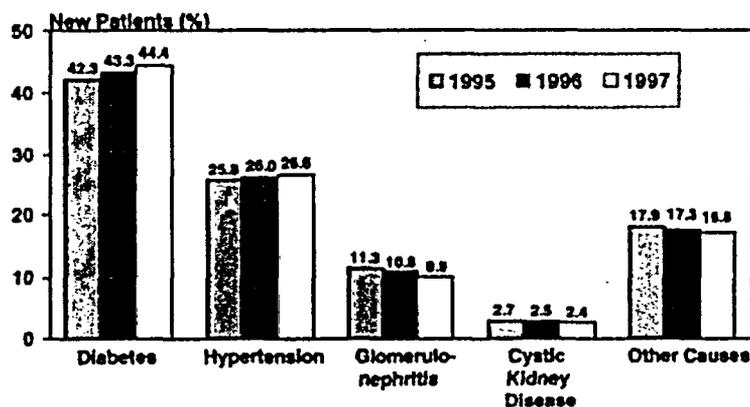
### Relative Prevalence of Treated ESRD compared to Caucasians: Data from the USRDS and other large data sets –

	1980's	1990's	Reference:
Hispanics	4.0 – 6.0		
African-Americans	3.5	5.0	
Native-Americans Zuni Navajo	2.8 8.6	7.0 3 – (95 x for 20-44 yr-olds)	Newman et al, Am J Pub H 80: 318, 1990 *Dyck CMAJ 1994 Pasinski Arch Int Med 1987 Narva AJKD 2000

### Selected observations regarding prevalence of ESRD:

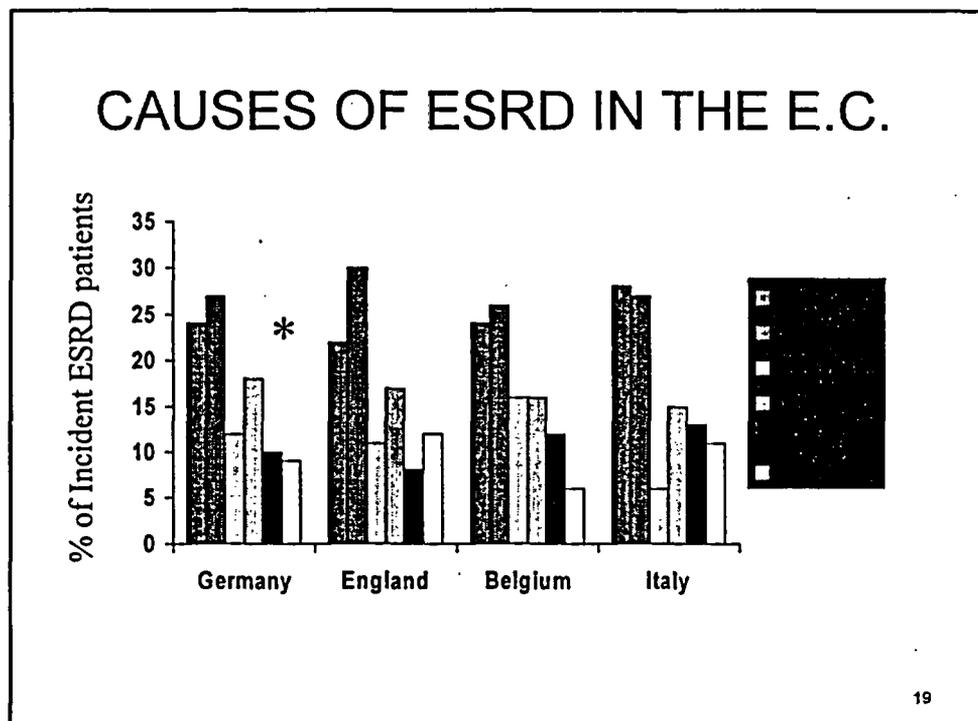
- ESRD occurs at a younger age (Narva 2000)
  - 6.7% of 20 – 44 yr-olds with ESRD vs 0.07 % for Whites
  - 15.9 % of individuals  $\geq$  45 yr-old with ESRD
- Prevalence of proteinuria without diabetic renal disease is 4 fold for similar populations (Hoy AJKD 1996)
- Prevalence rates for Diabetes Mellitus also increased (Age adjusted approximately 2 fold higher)

17



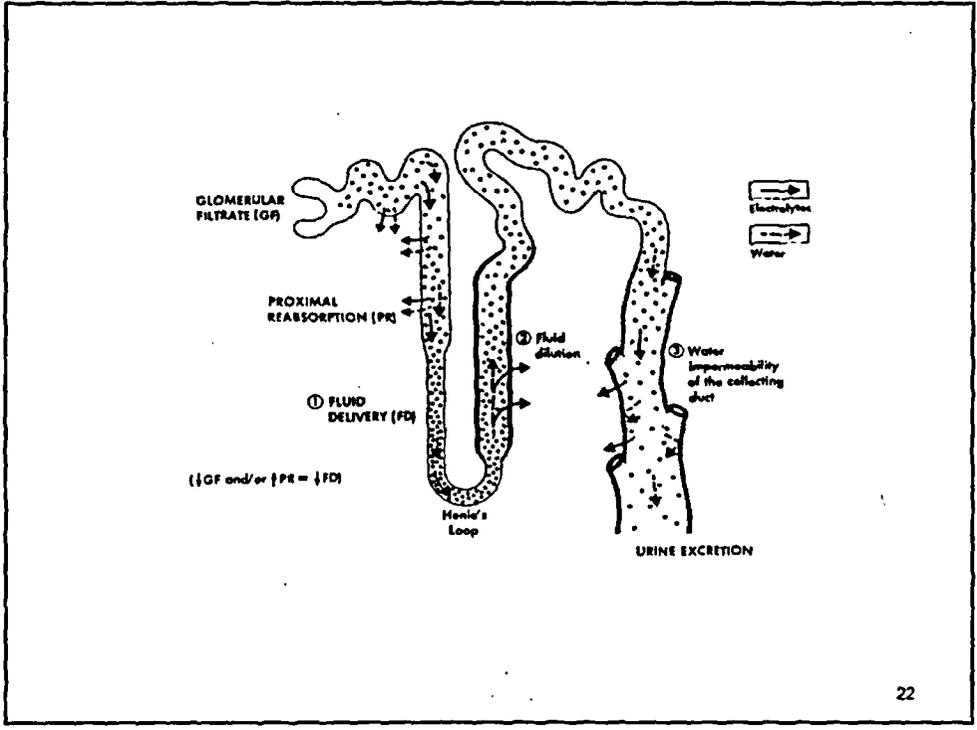
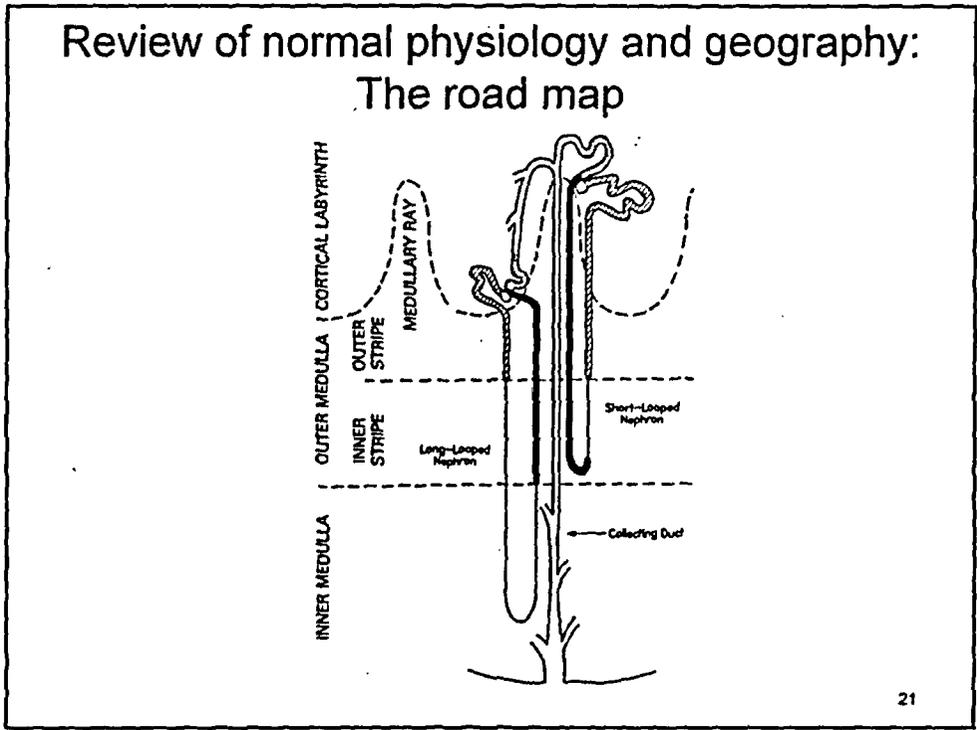
**Fig IV-5. Distribution of primary disease among new patients by year as reported on the HCFA Medical Evidence Form, 1995 to 1997. Percentages within each year sum to 100. Unknown causes of ESRD included in other causes; patients whose cause of ESRD is missing are excluded. Source: Reference Table L.20.**

18



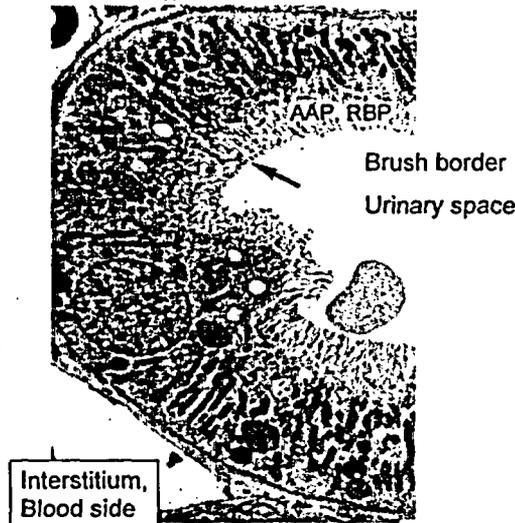
What are the factors that mediate the increased risk of ESRD for the population as a whole; for more vulnerable populations?

- The extent and progression of tubulo-interstitial fibrosis (TIF)
- Interaction of TIF with glomerulonephritis as might occur in individuals with diabetic nephropathy
- Physiologic effects from residence in the southwest
- Acute and chronic exposure to tubular toxicants that injure the tubule.



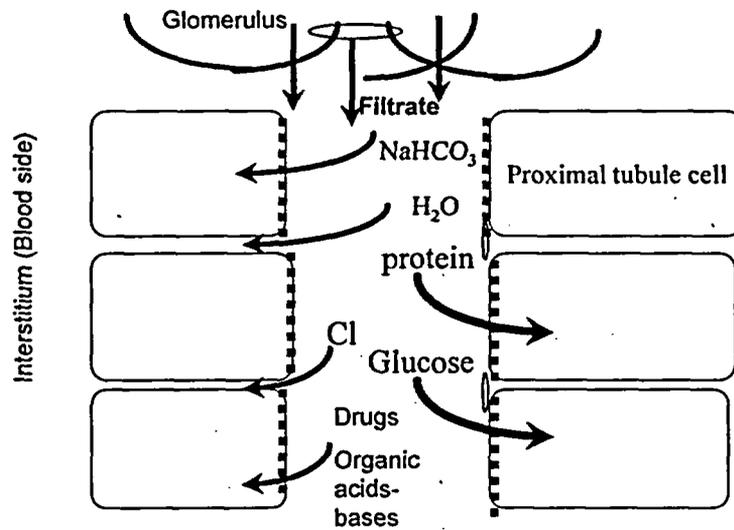
### The proximal tubular cell

Histology Lab Part 16: Slide 57



23

### PHYSIOLOGIC FUNCTIONS OF THE PROXIMAL TUBULE



24

### FACTORS THAT WILL INCREASE TOXICITY

- Increased cellular uptake of the toxicant
- Decreased metabolism to inactive products
- Decrease cysteine and glutathione stores
- Increased cellular hypoxia
- Prior renal damage / decreased reserve
- Obstructive nephropathy/ chronic pyelonephritis
- Volume depletion
- Increased proximal tubular reabsorption
- Decreased delivery to/ increased NaCl absorption by the mTAL
- Saturation of /Competition for detoxification pathways
- Activation of mixed function oxidases

25

### Physiologic factors that increase proximal tubule absorption

- Dehydration
- Dehydration
- Dehydration
  
- Neutral substances
- Charge
- Specialized transporters
- Absence of competing substances
- Age

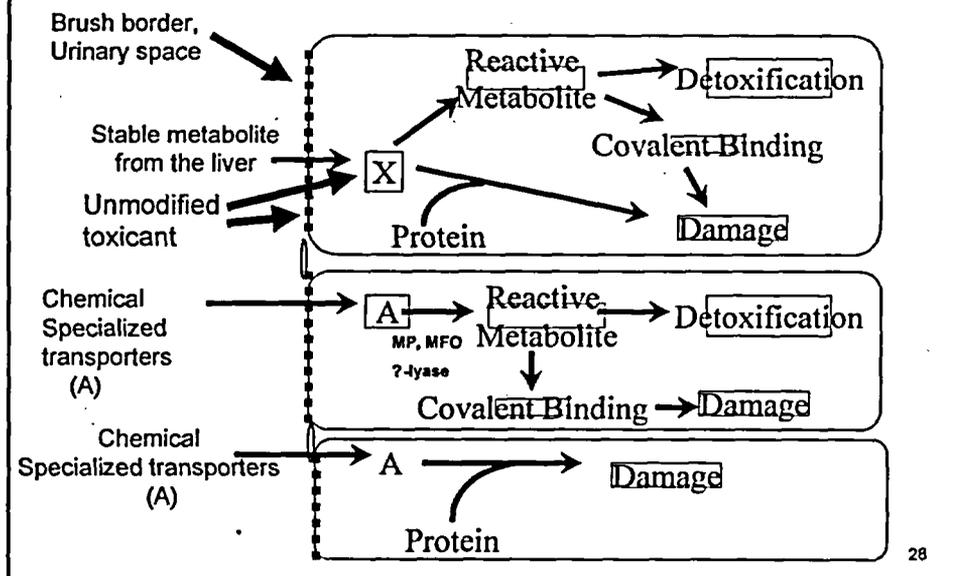
26

## PROXIMAL TUBULAR METABOLIC FUNCTIONS

- Mixed Function Oxidases
- Metallothionein
- Beta-lyase
- Organic Anion transporters
- Glutathione conjugation
- Amino acid transporters
- Metallothionein
- Lysosomal enzymes

27

### Reabsorptive processes of the Proximal Tubule Cells that mediate injury



28

## ACUTE VERSUS CHRONIC INJURY

### ACUTE

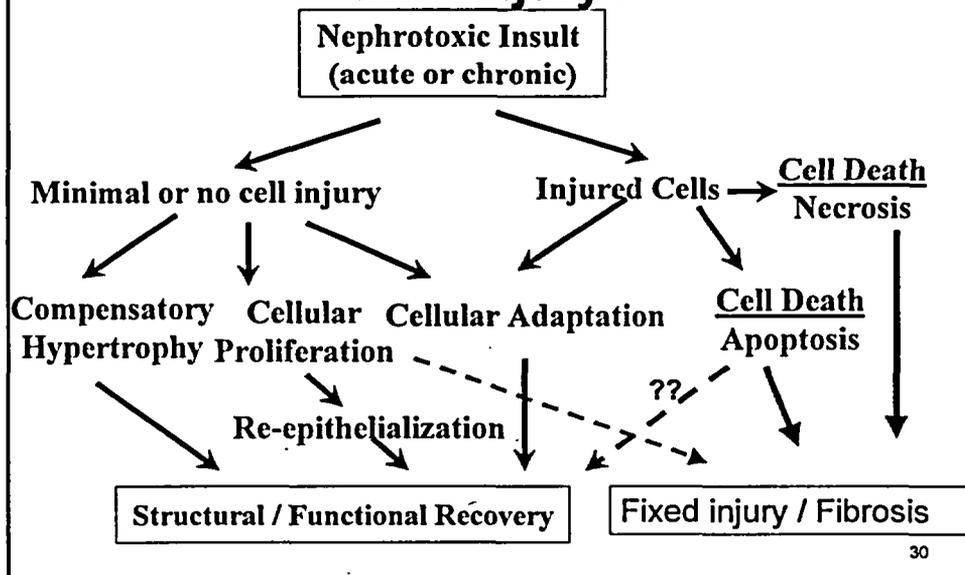
- Frequently results in pan-tubular necrosis
- Manifest often as acute renal failure but may be self limiting
- Often in association with a massive toxicant exposure
- Easily recognized (but difficult to dx)

### CHRONIC

- Usually results in site specific injury
- Manifest as tubular dysfunction and chronic renal insufficiency
- Lower doses of toxicants
- Difficult to recognize and to diagnose

29

## What is the fate of the proximal tubule after injury?



30

## Pathophysiology of Interstitial Fibrosis

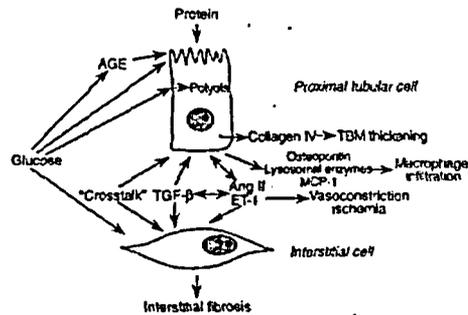
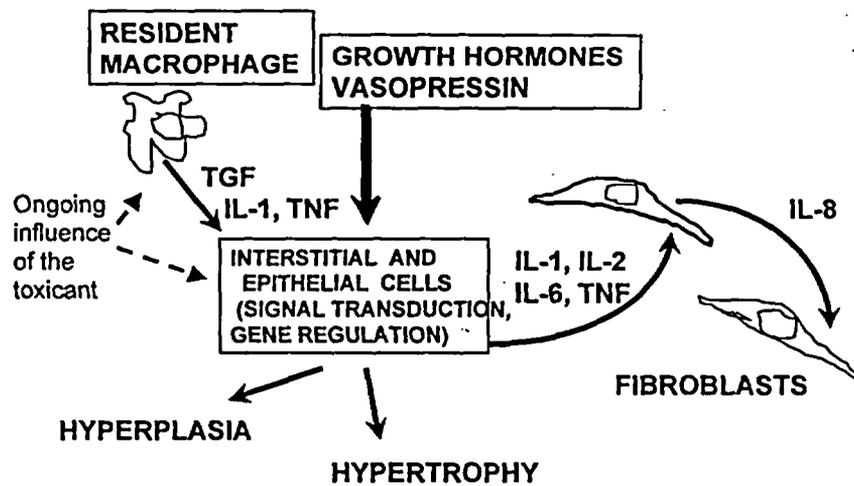


Fig. 5. A schema suggesting a complex series of interactions between interstitial and proximal tubular cells involving vasoactive hormones, glucose-dependent pathways such as polyols and advanced glycation end products (AGEs), and cytokines such as transforming growth factor- $\beta$  (TGF- $\beta$ ), leading to tubular basement membrane thickening, macrophage infiltration, and tubulointerstitial fibrosis.

31

## FACTORS CONTRIBUTING TO CHRONIC TUBULOINTERSTITIAL NEPHRITIS/FIBROSIS



32

Examples of toxicants that are more likely to produce injury after repeated or prolonged exposure

Prolonged Exposure

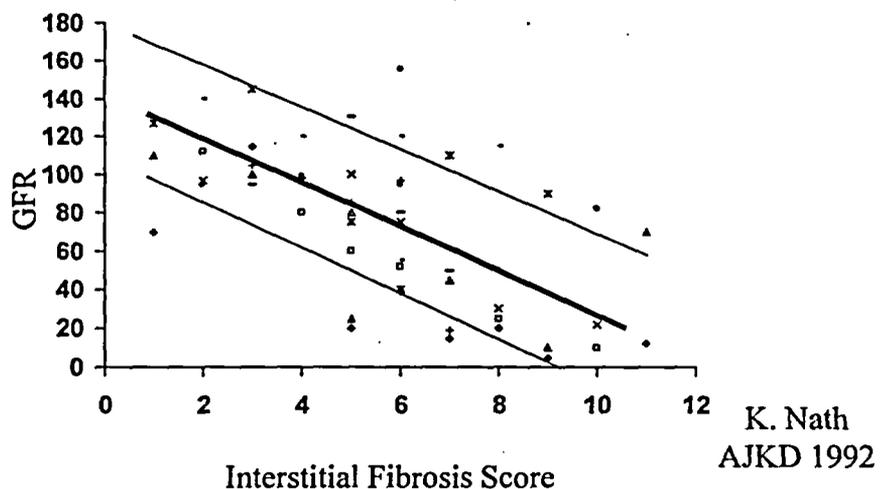
- NSAID (aspirin like agents)
- Lithium

Repeated Exposure

- Chemotherapeutic agents
  - Ifosfamide
  - Cis-Platinin
- Radiologic constrast
- Certain anti-microbial agents / anti-virals

33

Interstitial Fibrosis and Kidney Failure



34

## Interstitial Fibrosis and Progression of Renal Disease

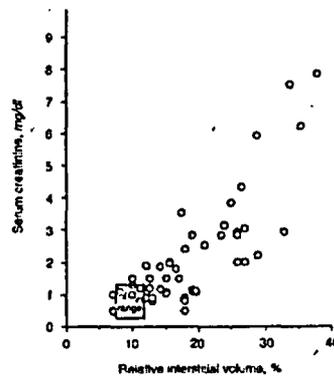


Fig. 1. Relationship between serum creatinine concentration (vertical axis) at the time of biopsy and relative interstitial volume (horizontal axis) in diabetic nephropathy. The normal (0) range is indicated by the square. (Reprinted with permission from the International Society of Nephrology [1] and *Pathology Research and Practice* 167:214-216, 1980 [15].)

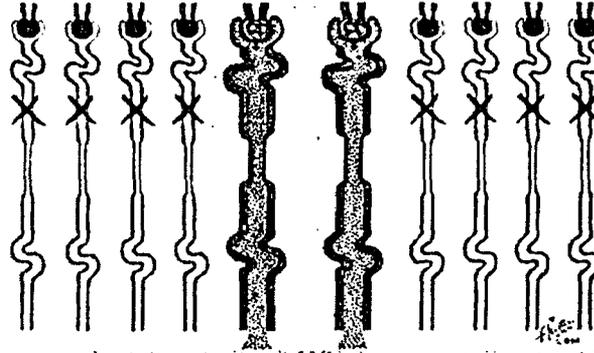
35

## Interactions Between Glomerular Diseases and Tubular Interstitial Nephritis

- **TIN resulting in decreased GFR- Glomerular Injury**
  - Tubulo-glomerular feedback (Acute renal success with increased renal ischemia)
  - Increased production of cytokines and other pro-fibrotic mediators
  - Increased production of vasoconstrictors
  - Atubular glomeruli
  
- **Glomerulonephritis / Glomerular disease causing TIN**
  - Increased delivery of protein and other toxicants to the proximal tubule cell

36

## Decreased Nephron Mass



37

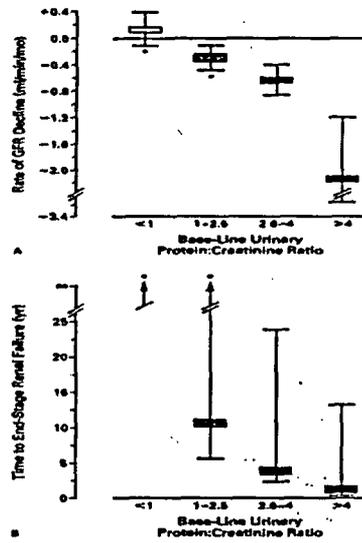


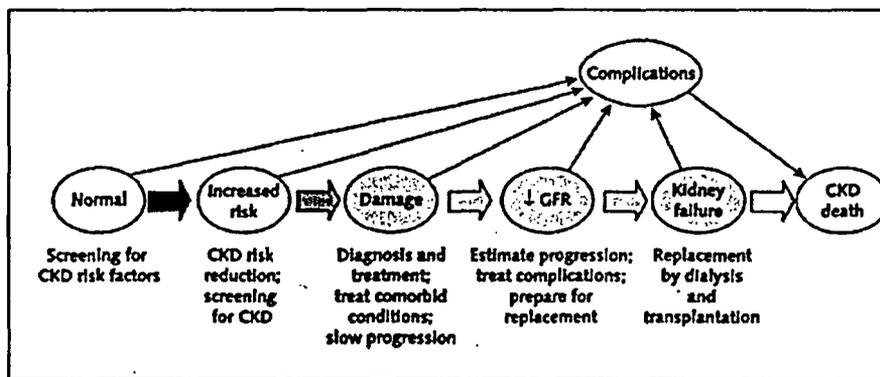
Figure 3. Mean (±SE) Rate of Decline in the Glomerular Filtration Rate (GFR) per Patient per Month (Panel A) and Mean Predicted Time to End-Stage Renal Disease (Panel B) According to Base-Line Ratio of Urinary Protein to Creatinine in 89 Patients with Chronic Nondiabetic, Proteinuric Nephropathies. Asterisks Indicate a significant difference ( $P < 0.05$ ) from a base-line urinary protein:creatinine ratio above 4. The 1 bars in Panel B are ranges.

38

## Accelerated progression with multiple co-morbidities

- Co-occurrence of proteinuric renal disease or diabetic renal disease with another primary injury results in acceleration of that injury.
  - Examples:
    - Chronic acetaminophen and NSAID exposures associated with a much more rapid progression to CRF in individuals with diabetes or hypertension
    - Chronic Lithium administration

39



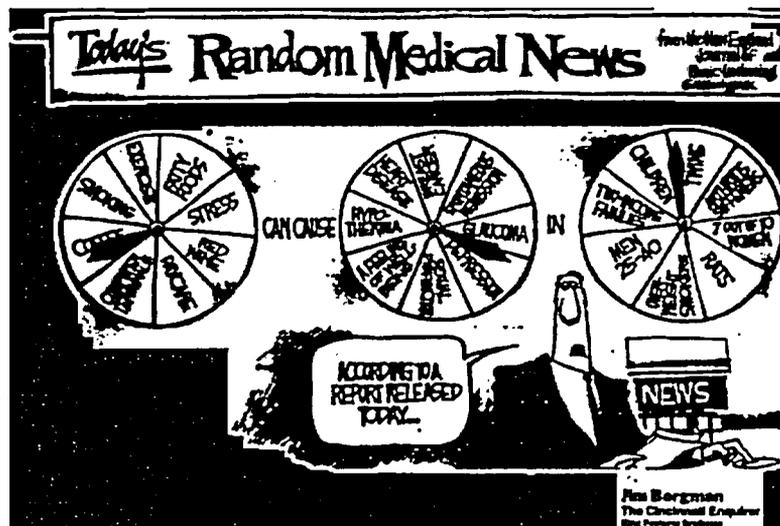
40

## Uranium and Kidney Disease

- Acute intoxication exposures (accidental or industrial)
- Acute exposure in healthy populations
- Chronic low level exposure as a primary cause of slowly progressive renal failure (observable over 20+ years)
- Chronic low level exposure as an enabling or accelerating factor in individuals with other kidney disease risk

How can one provide evidence for the adverse effects chronic long-term exposure to uranium and the magnitude of these effects to help guide Public Policy?

41



42

## Approaches to exclude other explanations:

- Design and analyze study to reduce eliminate competing explanations
  - (Experimental studies are rarely possible)
- Well designed large observational studies
- Evaluate findings for the strength of the inference using the criteria described by Sir Austin Bradford-Hill and others

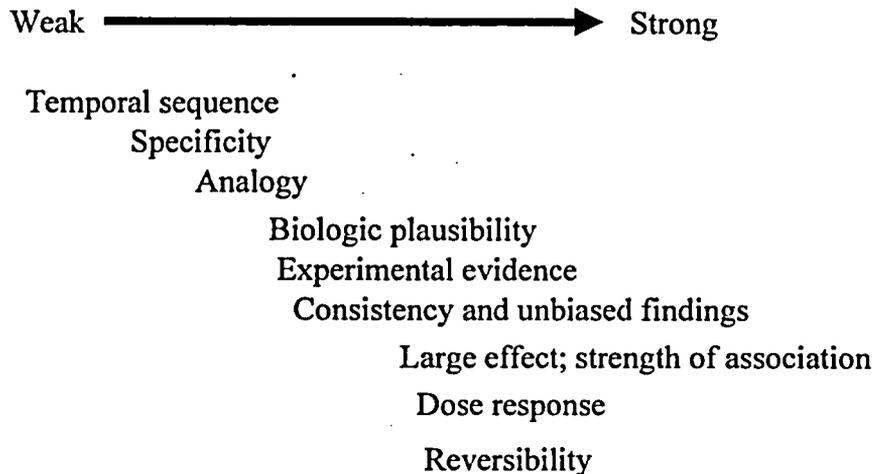
43

Important considerations when evaluating the rigor of the observations. Study subjects/ exposure measures.

- Selection and ascertainment biases
- Are the subjects studied likely to be representative of the population of interest?
- Are we measuring the correct variable or exposure? Is the variable measured sufficiently representative of the exposure of interest? Consider intermediate exposure measures to provide answers early for an exposure expected to have late effects.

44

**Bradford Hill criteria for causation;  
Strength of the evidence:**



45

**Recent human population-based  
observational studies (cohort or case-  
control study design):**

- Mao, Environ Res 1995– Chronic exposure and microalbuminuria (proteinuria)
- Zamora, Tox Sc 1998 – Increased proximal tubule proteins in the urine without overt kidney failure at the time of observation (healthy population effect; subjects with renal disease were excluded)
- Kurttio Environ Health Perspect 2002 – Cross sectional population study – Evidence of proximal and TALH tubular dysfunction

46

### Recommendations from an Evidence-Based and Medical Perspective

- Ethical imperative – Explicitly recognize the risk of the individuals in the population of interest and optimally minimize harm
- Evidence-Based Medicine imperative: Judicious use of best available evidence to determine intervention.

47

### Recommendations from an Evidence-Based and Medical Perspective

- My interpretation of the best available evidence is
  - That the risk is increased for individuals living in semi-arid environments; especially those with barriers to good preventative health care
  - That the risk is substantially increased for individuals with diabetes, hypertension, pre-existing kidney disease, cardiac disease and other medical conditions
  - That an increased susceptibility of 5 to 10 fold (factor of 10) is consistent with increased risks seen with other similar types of exposures.

48

### Recommendations from an Evidence-Based and Medical Perspective

- I believe that the specific recommendations by Toth et al are based on a fair and unbiased evaluations of the medical literature and in my medical judgment, I believe that their interpretation of the unique risks of individuals residing in certain locations in New Mexico is medically and scientifically sound.
- I agree with the recommendation to lower the allowable uranium in regulated ground-water sources to  $< 0.007 \text{ mg / L}$

49

Baseline Groundwater Concentrations (mg/l) - Section 9, T17N, R13W, Wells (March 13, 1978)

Parameter	Dakota	Westwater Canyon									
	207	208	210	213	214	215	218	220	221	222	224
Bicarbonate	195	208	177	170	213	204	182	207	217	219	200
Aluminum	1.6	1.2	1.6	0.8	0.5	0.6	0.9	0.8	0.8	0.8	1.1
Arsenic	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium	<0.1	0.14	<0.1	<0.1	0.13	0.14	<0.1	<0.1	<0.1	<0.1	<0.1
Boron	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Cadmium	0.002	<0.001	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.003
Calcium	24.0	70.2	18.2	4.5	3.2	20.4	6.6	3.8	7.6	3.6	4.1
Carbonate	0	0	0	0	0	0	0	0	0	0	0
Chloride	56.8	146.	61.2	12.5	25.1	96.7	15.1	16.1	13.1	10.7	15.6
Chromium	0.001	<0.001	0.001	0.004	<0.001	0.002	<0.001	0.004	0.004	0.002	0.003
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	0.017	0.003	0.002	0.002	<0.001	<0.001	0.001	0.010	0.002	0.002	0.003
Cyanide	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoride	0.36	0.82	0.49	0.69	0.29	0.61	0.57	0.29	0.32	0.29	0.25
Iron	8.0	7.2	8.5	0.75	0.44	3.7	1.6	8.2	0.4	1.1	8.2
Lead	0.007	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
Magnesium	15	2.7	3.1	0.47	0.36	1.3	0.73	0.49	0.22	0.55	0.92
Manganese	0.25	0.94	0.38	0.054	0.029	0.50	0.14	0.085	0.13	0.071	0.071
Mercury, Total	<0.0004	0.0050	0.0055	0.0053	0.0048	0.0025	0.0046	0.0048	0.005	<0.0004	<0.0004
Molybdenum	<0.001	0.013	0.002	0.004	0.003	0.005	0.004	0.003	0.001	0.003	0.004
Nickel	<0.01	<0.01	<0.01	<0.01	<0.01	0.012	0.012	0.057	<0.01	<0.01	<0.01
Nitrogen, Ammonia	0.26	0.04	<0.01	0.01	<0.01	0.02	<0.01	<0.01	0.03	<0.01	<0.01
Nitrogen, Nitrate	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
pH	7.0	6.6	7.0	7.1	8.3	7.0	7.2	7.8	8.0	8.3	7.9
Phenols	0.008	0.004	0.010	0.044	0.005	0.006	0.003	0.014	0.002	0.003	<0.001
Potassium	3.6	1.4	0.9	0.8	0.7	1.0	0.7	0.8	0.5	0.5	0.5
Selenium	<0.01	0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica	28.8	25.7	27.4	36.7	22.9	28.3	28.2	22.5	22.8	24.7	25.1
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sodium	120	95	80	62	100	88	91	100	100	110	89
Solids, Total											
Dissolved	676	536	380	331	398	522	381	347	367	350	330
Specific Conductance (umhos/cm)	930	823	502	483	465	800	438	378	454	447	443
Strontium	2.09	2.14	1.47	0.33	0.30	0.84	0.25	0.34	0.18	0.16	0.14
Sulfate	272	34	38	38	36	33	31	32	38	39	37
Titanium	0.09	0.34	0.44	0.21	0.11	0.14	0.12	0.077	0.06	0.06	0.08
Total Organic Carbon	2.5	1.7	1.4	2.0	0.3	6.1	12.4	1.4	1.7	23.3	0.3
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.04	0.02	0.02	0.02	<0.01	0.04	<0.01	<0.01	0.02	<0.01	<0.01
Anion/Cation Ratio	0.81	1.10	0.92	0.95	1.13	1.09	1.10	1.02	1.02	0.99	1.18



Table 2.7-3 HRI's Ground Water Quality Summary

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY

WELL CP-1

PARAMETER	6-21-90
CALCIUM	1.4
MAGNESIUM	0.34
SODIUM	138
POTASSIUM	5.9
CARBONATE	53
BICARBONATE	170
SULFATE	50
CHLORIDE	15
NITRATE	0.01
FLUORIDE	0.57
SILICA	2
TDS	380
CONDUCTIVITY	611
ALKALINITY	227
PH	9.61
ARSENIC	<.001
BARIUM	0.04
CADMIUM	<.0001
CHROMIUM	<.01
COPPER	<.01
IRON	0.02
LEAD	<.001
MANGANESE	<.01
MERCURY	<.0001
MOLYBDENUM	0.01
NICKEL	<.01
SELENIUM	<.001
SILVER	<.01
URANIUM	0.006
VANADIUM	<.01
ZINC	<.01
BORON	0.11
AMMONIA	<.01
RADIUM 226	0.9



Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-2

PARAMETER	9-5-90	5-22-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	123	132	114		123	7	114	132
MAGNESIUM	13	11	14		13	1	11	14
SODIUM	342	266	326		311	33	266	342
POTASSIUM	904	820	760		828	59	760	904
CARBONATE	0	0	0		0	0	0	0
BICARBONATE	183	177	156		172	12	156	183
SULFATE	73	73	62		69	5	62	73
CHLORIDE	1486	1230	1341		1,352	105	1230	1486
NITRATE	0.02	0.01	0.2		0.08	0.09	0.01	0.2
FLUORIDE	0.36	0.65	0.42		0.48	0.12	0.36	0.65
SILICA	16	17	16		16	0	16	17
TDS	3190	2730	2830		2,917	198	2730	3190
CONDUCTIVITY	5360	4750	4960		5,023	253	4750	5360
ALKALINITY	150	145	128		141	9	128	150
PH	7.86	7.92	7.85		7.88	0.03	7.85	7.92
ARSENIC	<.001	<.001	0.001		0.000	0.000	0	0.001
BARIUM	1	0.45	0.74		0.73	0.22	0.45	1
CADMIUM	<.0001	<.0001	0.0008		0.0003	0.0004	0	0.0008
CHROMIUM	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01		0.00	0.00	0	0
IRON	0.36	0.92	0.28		0.52	0.28	0.28	0.92
LEAD	0.013	<.001	0.002		0.005	0.006	0	0.013
MANGANESE	0.29	0.21	0.15		0.22	0.06	0.15	0.29
MERCURY	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	0.01	0.02	<.01		0.01	0.01	0	0.02
NICKEL	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	0.021	0.013	0.008		0.014	0.005	0.008	0.021
VANADIUM	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	0.01	<.01	0.03		0.01	0.01	0	0.03
BORON	0.07	0.09	0.08		0.08	0.01	0.07	0.09
AMMONIA	<.01	0.04	0.1		0.05	0.04	0	0.1
RADIUM 226	806	128	492		475.3	277.0	128	806

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-3

PARAMETER	6-21-90	9-6-90	5-22-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	1.3	4.2	7.8	6.6		5.0	2.5	1.3	7.8
MAGNESIUM	0.14	1.9	2.2	2.5		1.7	0.9	0.14	2.5
SODIUM	115	166	184	180		161	28	115	184
POTASSIUM	4.7	56	52	52		41	21	4.7	56
CARBONATE	49	1	12	7		17	19	1	12
BICARBONATE	161	260	245	251		229	40	161	260
SULFATE	21	158	177	175		133	65	21	177
CHLORIDE	13	52	54	48		42	17	13	54
NITRATE	<.01	0.03	0.01	0.24		0.07	0.10	0	0.24
FLUORIDE	0.36	0.45	0.5	0.45		0.44	0.05	0.36	0.5
SILICA	1	16	17	19		13	7	1	19
TDS	308	632	666	661		567	150	308	666
CONDUCTIVITY	487	961	999	1040		872	224	487	1040
ALKALINITY	214	215	221	218		217	3	214	221
PH	9.53	8.35	8.62	8.52		8.76	0.46	8.35	8.62
ARSENIC	<.001	<.001	<.001	<.001		0.000	0.000	0	0
BARIUM	0.03	0.03	0.04	0.02		0.03	0.01	0.02	0.04
CADMIUM	<.0001	<.0001	0.0002	<.0001		0.0000	0.0001	0	0.0002
CHROMIUM	<.01	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01	<.01		0.00	0.00	0	0
IRON	0.03	0.03	0.11	0.13		0.08	0.05	0.03	0.13
LEAD	<.001	<.001	<.001	<.001		0.000	0.000	0	0
MANGANESE	<.01	0.02	0.02	0.01		0.01	0.01	0	0.02
MERCURY	<.0001	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	0.01	<.01	<.01	<.01		0.00	0.00	0	0
NICKEL	<.01	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	0.001	<.001	0.013	<.001		0.004	0.006	0	0.013
VANADIUM	<.01	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	<.01	0.01		0.00	0.00	0	0.01
BORON	0.05	0.11	0.09	0.09		0.09	0.02	0.05	0.11
AMMONIA	<.01	0.07	0.17	0.04		0.07	0.06	0	0.17
RADIUM 226	0.8	1.9	2.1	2.5		1.8	0.6	0.8	2.5

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-4

PARAMETER	6-20-90
CALCIUM	0.7
MAGNESIUM	0.03
SODIUM	132
POTASSIUM	9.2
CARBONATE	140
BICARBONATE	9
SULFATE	45
CHLORIDE	6
NITRATE	0.01
FLUORIDE	0.3
SILICA	9
TDS	371
CONDUCTIVITY	661
ALKALINITY	241
PH	10.36
ARSENIC	<.001
BARIUM	0.06
CADMIUM	<.0001
CHROMIUM	<.01
COPPER	<.01
IRON	0.03
LEAD	<.001
MANGANESE	<.01
MERCURY	<.0001
MOLYBDENUM	<.01
NICKEL	<.01
SELENIUM	<.001
SILVER	<.01
URANIUM	<.001
VANADIUM	<.01
ZINC	<.01
BORON	0.06
AMMONIA	0.17
RADIUM 226	0.8

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-5

PARAMETER	6-21-90	5-22-91	8-5-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	1.5	3.9	2.9	2.8		2.8	0.9	1.5	3.9
MAGNESIUM	0.1	0.2	0.22	0.24		0.19	0.05	0.1	0.24
SODIUM	103	97	97	104		100	3	97	104
POTASSIUM	1.5	1.8	1.7	1.8		1.7	0.1	1.5	1.8
CARBONATE	4	10	0	10		6	4	0	10
BICARBONATE	228	215	229	215		222	7	215	229
SULFATE	41	19	40	38		35	9	19	41
CHLORIDE	2	2	2.5	2.9		2.4	0.4	2	2.9
NITRATE	0.04	<0.01	0.01	<0.01		0.01	0.02	0	0.04
FLUORIDE	0.25	0.27	0.26	0.23		0.25	0.01	0.23	0.27
SILICA	16	18	18	20		18	1	16	20
TDS	303	281	300	308		298	10	281	308
CONDUCTIVITY	458	418	443	452		443	15	418	458
ALKALINITY	193	192	191	192		192	1	191	193
PH	8.44	8.66	8.26	8.64		8.50	0.16	8.26	8.66
ARSENIC	<.001	<.001	<.001	0.001		0.000	0.000	0	0.001
BARIUM	0.05	0.09	0.11	0.07		0.080	0.022	0.05	0.11
CADMIUM	<.0001	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
CHROMIUM	<.01	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01	<.01		0.00	0.00	0	0
IRON	0.04	<.01	0.04	0.04		0.03	0.02	0	0.04
LEAD	0.001	<.001	0.001	<.001		0.000	0.000	0	0.001
MANGANESE	<.01	0.01	0.01	0.01		0.01	0.00	0	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	<.01	<.01	<.01	<.01		0.00	0.00	0	0
NICKEL	<.01	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	0.013	0.012	0.012	0.011		0.012	0.001	0.011	0.013
VANADIUM	<.01	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	0.01	<.01		0.00	0.00	0	0.01
BORON	0.03	0.03	0.03	0.05		0.04	0.01	0.03	0.05
AMMONIA	<.01	<.01	0.01	0.02		0.01	0.01	0	0.02
RADIUM 226	0.3	1	1.1	1.8		1.1	0.5	0.3	1.8

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-6

PARAMETER	5-22-91	8-55-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	2.3	1.2	1.3		1.6	0.5	1.2	2.3
MAGNESIUM	0.08	0.04	0.09		0.07	0.02	0.04	0.09
SODIUM	113	106	109		109	3	106	113
POTASSIUM	2.6	2.4	2.4		2.5	0.1	2.4	2.6
CARBONATE	19	19	26		21	3	19	26
BICARBONATE	211	207	195		204	7	195	211
SULFATE	36	36	34		35	1	34	36
CHLORIDE	3.4	2.9	3		3.1	0.2	2.9	3.4
NITRATE	0.02	<.01	<.01		0.01	0.01	0	0.02
FLUORIDE	0.25	0.25	0.23		0.24	0.01	0.23	0.25
SILICA	15	16	18		16	1	15	18
TDS	317	307	316		313	4	307	317
CONDUCTIVITY	477	467	471		472	4	467	477
ALKALINITY	205	202	204		204	1	202	205
PH	8.82	8.88	9.19		8.96	0.16	8.82	9.19
ARSENIC	<.001	<.001	0.001		0.000	0.000	0	0.001
BARIUM	0.05	0.04	0.04		0.04	0.00	0.04	0.05
CADMIUM	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
CHROMIUM	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01		0.00	0.00	0	0
IRON	0.02	0.1	0.03		0.05	0.04	0.02	0.1
LEAD	<.001	0.001	<.001		0.000	0.000	0	0.001
MANGANESE	0.01	<.01	<.01		0.00	0.00	0	0.01
MERCURY	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	<.01	<.01	<.01		0.00	0.00	0	0
NICKEL	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	<.001	<.001	0.001		0.000	0.000	0	0.001
VANADIUM	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	0.01		0.00	0.00	0	0.01
BORON	0.02	<.01	0.04		0.02	0.02	0	0.04
AMMONIA	0.02	0.01	0.04		0.02	0.01	0.01	0.04
RADIUM 226	0.4	0.4	0.7		0.5	0.1	0.4	0.7

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-7

PARAMETER	9-6-90	5-22-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	2.2	0.07	0.07		0.8	1.0	0.07	2.2
MAGNESIUM	0.13	<.01	0.01		0.05	0.06	0	0.13
SODIUM	110	123	118		117	5	110	123
POTASSIUM	2.1	12	4.9		6.3	4.2	2.1	12
CARBONATE	14	127	76		72	46	14	127
BICARBONATE	224	54	118		132	70	54	224
SULFATE	38	21	35		31	7	21	38
CHLORIDE	1.8	2.9	3.6		2.8	0.7	1.8	3.6
NITRATE	0.26	0.21	0.08		0.18	0.08	0.08	0.26
FLUORIDE	0.39	0.52	0.62		0.51	0.09	0.39	0.62
SILICA	17	13	.19		16	2	13	19
TDS	318	355	338		337	15	318	355
CONDUCTIVITY	490	605	529		541	48	490	605
ALKALINITY	208	256	223		229	20	208	256
PH	8.67	10.35	9.92		9.65	0.71	8.67	10.35
ARSENIC	<.001	0.001	0.002		0.001	0.001	0	0.002
BARIUM	0.03	0.01	0.01		0.02	0.01	0.01	0.03
CADMIUM	0.0003	0.0001	<.0001		0.0001	0.0001	0	0.0003
CHROMIUM	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	0.02	0.02		0.01	0.01	0	0.02
IRON	0.01	0.21	0.12		0.11	0.08	0.01	0.21
LEAD	<.001	0.002	0.002		0.001	0.001	0	0.002
MANGANESE	0.01	<.01	<.01		0.00	0.00	0	0.01
MERCURY	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	<.01	0.01	0.01		0.01	0.00	0	0.01
NICKEL	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	0.001	0.001	0.001		0.001	0.000	0.001	0.001
VANADIUM	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	<.01		0.00	0.00	0	0
BORON	0.07	0.05	0.06		0.06	0.01	0.05	0.07
AMMONIA	<.01	0.31	0.18		0.16	0.13	0	0.31
RADIUM 226	0.5	0.2	0.6		0.4	0.2	0.2	0.6

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-8

PARAMETER	8-20-90	5-22-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	2.7	2.7	2		2.5	0.3	2	2.7
MAGNESIUM	0.12	0.15	0.18		0.15	0.02	0.12	0.18
SODIUM	118	110	107		112	5	107	118
POTASSIUM	2	2.3	2.3		2.2	0.1	2	2.3
CARBONATE	41	19	18		26	11	18	41
BICARBONATE	184	210	214		203	13	184	214
SULFATE	47	34	34		38	6	34	47
CHLORIDE	3.2	3.3	3.5		3.3	0.1	3.2	3.5
NITRATE	0.03	0.05	<.01		0.03	0.02	0	0.05
FLUORIDE	0.31	0.29	0.25		0.28	0.02	0.25	0.31
SILICA	13	15	18		15	2	13	18
TDS	339	312	313		321	12	312	339
CONDUCTIVITY	529	471	463		488	29	463	529
ALKALINITY	219	204	205		209	7	204	219
PH	9.34	8.91	8.97		9.07	0.19	8.91	9.34
ARSENIC	<.001	<.001	<.001		0.000	0.000	0	0
BARIUM	0.03	0.09	0.07		0.06	0.02	0.03	0.09
CADMIUM	0.0002	<.0001	<.0001		0.0001	0.0001	0	0.0002
CHROMIUM	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01		0.00	0.00	0	0
IRON	0.06	0.05	0.05		0.05	0.00	0.05	0.06
LEAD	0.002	0.001	0.001		0.001	0.000	0.001	0.002
MANGANESE	0.01	0.02	0.01		0.01	0.00	0.01	0.02
MERCURY	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	0.02	<.01	<.01		0.01	0.01	0	0.02
NICKEL	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	0.006	0.006	0.002		0.005	0.002	0.002	0.006
VANADIUM	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	<.01		0.00	0.00	0	0
BORON	0.07	0.05	0.05		0.06	0.01	0.05	0.07
AMMONIA	<.01	0.03	<.01		0.01	0.01	0	0.03
RADIUM 226	0.6	0.9	0.9		0.8	0.1	0.6	0.9

Table 2.7-3 HRI's Ground Water Quality Summary (Cont)

WELL CP-10(DAKOTA FM.)

PARAMETER	5-22-91	8-5-91	10-22-91	WINTER	AVG.	STD.	MIN.	MAX
CALCIUM	2.1	1.9	1.9		2.0	0.1	1.9	2.1
MAGNESIUM	0.15	0.11	0.17		0.14	0.02	0.11	0.17
SODIUM	229	217	231		226	6	217	231
POTASSIUM	3.8	2	1.5		2.4	1.0	1.5	3.8
CARBONATE	46	16	34		32	12	16	46
BICARBONATE	214	243	210		222	15	210	243
SULFATE	227	251	251		243	11	227	251
CHLORIDE	3.9	9.6	5.3		6.3	2.4	3.9	9.6
NITRATE	<.01	0.01	0.04		0.02	0.02	0	0.04
FLUORIDE	0.72	0.57	0.55		0.61	0.08	0.55	0.72
SILICA	3	14	17		11	6	3	17
TDS	671	679	688		679	7	671	688
CONDUCTIVITY	1000	981	988		990	8	981	1000
ALKALINITY	251	225	228		235	12	225	251
PH	9.31	8.81	9.07		9.06	0.20	8.81	9.31
ARSENIC	<.001	<.001	<.001		0.000	0.000	0	0
BARIUM	0.02	0.01	0.05		0.03	0.02	0.01	0.05
CADMIUM	<0.0001	<0.0001	<0.0001		0.0000	0.0000	0	0
CHROMIUM	<.01	<.01	<.01		0.00	0.00	0	0
COPPER	<.01	<.01	<.01		0.00	0.00	0	0
IRON	<.01	0.13	0.06		0.06	0.05	0	0.13
LEAD	<.001	<.001	0.004		0.001	0.002	0	0.004
MANGANESE	0.01	0.01	0.01		0.01	0.00	0.01	0.01
MERCURY	<.0001	<.0001	<.0001		0.0000	0.0000	0	0
MOLYBDENUM	0.01	0.01	<.01		0.01	0.00	0	0.01
NICKEL	<.01	<.01	<.01		0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001		0.000	0.000	0	0
SILVER	<.01	<.01	<.01		0.00	0.00	0	0
URANIUM	<.001	<.001	<.001		0.000	0.000	0	0
VANADIUM	<.01	<.01	<.01		0.00	0.00	0	0
ZINC	<.01	<.01	<.01		0.00	0.00	0	0
BORON	0.17	0.14	0.2		0.17	0.02	0.14	0.2
AMMONIA	0.08	0.03	0.03		0.05	0.02	0.03	0.08
RADIUM 226	0.5	0.6	0.4		0.5	0.1	0.4	0.6

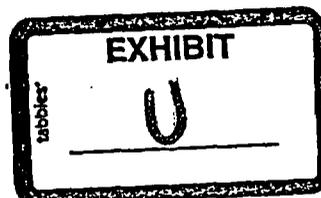


TABLE 2.3-3

HYDRO RESOURCES INC.  
 CROWNPOINT PROJECT  
 WATER QUALITY SUMMARY  
 WELL CP-1

PARAMETER	6-21-90
CALCIUM	1.4
MAGNESIUM	0.34
SODIUM	138
POTASSIUM	5.9
CARBONATE	53
BICARBONATE	170
SULFATE	50
CHLORIDE	15
NITRATE	0.01
FLUORIDE	0.57
SILICA	2
TDS	380
CONDUCTIVITY	611
ALKALINITY	227
PH	9.61
ARSENIC	<.001
BARIUM	0.04
CADMIUM	<.0001
CHROMIUM	<.01
COPPER	<.01
IRON	0.02
LEAD	<.001
MANGANESE	<.01
MERCURY	<.0001
MOLYBDENUM	0.01
NICKEL	<.01
SELENIUM	<.001
SILVER	<.01
URANIUM	0.006
VANADIUM	<.01
ZINC	<.01
BORON	0.11
AMMONIA	<.01
RADIUM 226	0.9



TABLE 2.3-4

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-2

PARAMETER	SUMMER 9-5-90	SPRING 5-22-91	FALL 10-22-91	WINTER 1-22-92	AVG.	STD.	MIN.	MAX
CALCIUM	123	132	114	109	120	9	109	132
MAGNESIUM	13	11	14	10	12	2	10	14
SODIUM	342	266	326	256	298	37	256	342
POTASSIUM	904	820	760	904	847	61	760	904
CARBONATE	0	0	0	0	0	0	0	0
BICARBONATE	183	177	156	168	171	10	156	183
SULFATE	73	73	62	71	70	5	62	73
CHLORIDE	1486	1230	1341	1244	1,325	102	1230	1486
NITRATE	0.02	0.01	0.2	0.02	0	0	0.01	0.2
FLUORIDE	0.36	0.65	0.42	0.47	0	0	0.36	0.65
SILICA	16	17	16	19	17	1	16	19
TDS	3190	2730	2830	2800	2,888	178	2730	3190
CONDUCTIVITY	5360	4750	4960	4840	4,978	233	4750	5360
ALKALINITY	150	145	128	138	140	8	128	150
PH	7.86	7.92	7.85	7.92	8	0	7.85	7.92
ARSENIC	<.001	<.001	0.001	0.001	0	0	0	0.001
BARIUM	1	0.45	0.74	0.43	1	0	0.43	1
CADMIUM	<.0001	<.0001	0.0008	<.0001	0	0	0	0.0008
CHROMIUM	<.01	<.01	<.01	<.01	0	0	0	0
COPPER	<.01	<.01	<.01	<.01	0	0	0	0
IRON	0.36	0.92	0.28	0.01	0	0	0.01	0.92
LEAD	0.013	<.001	0.002	<.001	0	0	0	0.013
MANGANESE	0.29	0.21	0.15	0.14	0	0	0.14	0.29
MERCURY	<.0001	<.0001	<.0001	<.0001	0	0	0	0
MOLYBDENUM	0.01	0.02	<.01	0.01	0	0	0	0.02
NICKEL	<.01	<.01	<.01	<.01	0	0	0	0
SELENIUM	<.001	<.001	<.001	<.001	0	0	0	0
SILVER	<.01	<.01	<.01	<.01	0	0	0	0
URANIUM	0.021	0.013	0.008	0.013	0	0	0.008	0.021
VANADIUM	<.01	<.01	<.01	<.01	0	0	0	0
ZINC	0.01	<.01	0.03	0.01	0	0	0	0.03
BORON	0.07	0.09	0.08	0.06	0	0	0.06	0.09
AMMONIA	<.01	0.04	0.1	0.07	0	0	0	0.1
RADIUM 226	806	128	492	139	391	281	128	806

TABLE 2.3-5

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-3

PARAMETER	SUMMER 6-21-90	SUMMER 9-6-90	SPRING 5-22-91	FALL 10-22-91	WINTER 1-23-92	AVG.	STD.	MIN.	MAX
CALCIUM	1.3	4.2	7.8	6.6	7.4	5.5	2.4	1.3	7.8
MAGNESIUM	0.14	1.9	2.2	2.5	2.2	1.7	0.9	0.14	2.5
SODIUM	115	166	184	180	173	161	28	115	184
POTASSIUM	4.7	56	52	52	51	41	21	4.7	56
CARBONATE	49	1	12	7	6	17	19	1	12
BICARBONATE	161	260	245	251	255	229	40	161	260
SULFATE	21	158	177	175	167	133	65	21	177
CHLORIDE	13	52	54	48	44	42	17	13	54
NITRATE	<.01	0.03	0.01	0.24	0.01	0.07	0.10	0	0.24
FLUORIDE	0.36	0.45	0.5	0.45	0.49	0.44	0.05	0.36	0.5
SILICA	1	16	17	19	20	13	7	1	19
TDS	308	632	666	661	637	567	150	308	666
CONDUCTIVITY	487	961	999	1040	950	872	224	487	1040
ALKALINITY	214	215	221	218	219	217	3	214	221
PH	9.53	8.35	8.62	8.52	8.59	8.76	0.46	8.35	8.62
ARSENIC	<.001	<.001	<.001	<.001	<.001	0.000	0.000	0	0
BARIUM	0.03	0.03	0.04	0.02	0.03	0.03	0.01	0.02	0.04
CADMIUM	<.0001	<.0001	0.0002	<.0001	<.0001	0.0001	0.0001	0	0.0002
CHROMIUM	<.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
COPPER	<.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
IRON	0.03	0.03	0.11	0.13	0.19	0.08	0.05	0.03	0.13
LEAD	<.001	<.001	<.001	<.001	<.001	0.000	0.000	0	0
MANGANESE	<.01	0.02	0.02	0.01	0.03	0.01	0.01	0	0.02
MERCURY	<.0001	<.0001	<.0001	<.0001	<.0001	0.0000	0.0000	0	0
MOLYBDENUM	0.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
NICKEL	<.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
SELENIUM	<.001	<.001	<.001	<.001	<.001	0.000	0.000	0	0
SILVER	<.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
URANIUM	0.001	<.001	0.013	<.001	<.001	0.004	0.006	0	0.013
VANADIUM	<.01	<.01	<.01	<.01	<.01	0.00	0.00	0	0
ZINC	<.01	<.01	<.01	0.01	<.01	0.00	0.00	0	0.01
BORON	0.05	0.11	0.09	0.09	0.07	0.09	0.02	0.05	0.11
AMMONIA	<.01	0.07	0.17	0.04	0.2	0.07	0.06	0	0.17
RADIUM 226	0.8	1.9	2.1	2.5	2.5	1.8	0.6	0.8	2.5

TABLE 2.3-6

HYDRO RESOURCES INC.  
 CROWNPOINT PROJECT  
 WATER QUALITY SUMMARY  
 WELL CP-4

PARAMETER	6-20-90
CALCIUM	0.7
MAGNESIUM	0.03
SODIUM	132
POTASSIUM	9.2
CARBONATE	140
BICARBONATE	9
SULFATE	45
CHLORIDE	6
NITRATE	0.01
FLUORIDE	0.3
SILICA	9
TDS	371
CONDUCTIVITY	661
ALKALINITY	241
PH	10.36
ARSENIC	<.001
BARIUM	0.06
CADMIUM	<.0001
CHROMIUM	<.01
COPPER	<.01
IRON	0.03
LEAD	<.001
MANGANESE	<.01
MERCURY	<.0001
MOLYBDENUM	<.01
NICKEL	<.01
SELENIUM	<.001
SILVER	<.01
URANIUM	<0.001
VANADIUM	<.01
ZINC	<.01
BORON	0.06
AMMONIA	0.17
RADIUM 226	0.8

TABLE 2.3-7

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-5

PARAMETER	SUMMER 6-21-90	SPRING 5-22-91	SUMMER 8-5-91	FALL 10-22-91	WINTER 1-20-92	AVG.	STD.	MIN.	MAX
CALCIUM	1.5	3.9	2.9	2.8	3.5	2.9	0.8	1.5	3.9
MAGNESIUM	0.1	0.2	0.22	0.24	0.22	0.2	0.0	0.1	0.24
SODIUM	103	97	97	104	107	101.6	4.0	97	107
POTASSIUM	1.5	1.8	1.7	1.8	1.8	1.7	0.1	1.5	1.8
CARBONATE	4	10	0	10	6	6.0	3.8	0	10
BICARBONATE	228	215	229	215	222	221.8	6.0	215	229
SULFATE	41	19	40	38	39	35.4	8.3	19	41
CHLORIDE	2	2	2.5	2.9	3.1	2.5	0.5	2	3.1
NITRATE	0.04	<0.01	0.01	<0.01	<0.01	0.0	0.0	0	0.04
FLUORIDE	0.25	0.27	0.26	0.23	0.25	0.3	0.0	0.23	0.27
SILICA	16	18	18	20	20	18.4	1.5	16	20
TDS	303	281	300	308	309	300.2	10.1	281	309
CONDUCTIVITY	458	418	443	452	449	444.0	13.9	418	458
ALKALINITY	193	192	191	192	192	192.0	0.6	191	193
PH	8.44	8.66	8.26	8.64	8.61	8.5	0.2	8.26	8.66
ARSENIC	<.001	<.001	<.001	0.001	0.001	0.0	0.0	0	0.001
BARIUM	0.05	0.09	0.11	0.07	0.08	0.1	0.0	0.05	0.11
CADMIUM	<.0001	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
CHROMIUM	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
IRON	0.04	<.01	0.04	0.04	0.03	0.0	0.0	0	0.04
LEAD	0.001	<.001	0.001	<.001	<.001	0.0	0.0	0	0.001
MANGANESE	<.01	0.01	0.01	0.01	0.01	0.0	0.0	0	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
NICKEL	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	0.013	0.012	0.012	0.011	0.012	0.0	0.0	0.011	0.013
VANADIUM	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	0.01	<.01	<.01	0.0	0.0	0	0.01
BORON	0.03	0.03	0.03	0.05	0.03	0.0	0.0	0.03	0.05
AMMONIA	<.01	<.01	0.01	0.02	0.02	0.0	0.0	0	0.02
RADIUM 226	0.3	1	1.1	1.8	0.9	1.0	0.5	0.3	1.8

TABLE 2.3-8

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-6

PARAMETER	SPRING 5-22-91	SUMMER 8-55-91	FALL 10-22-91	WINTER 1-21-92	AVG.	STD.	MIN.	MAX
CALCIUM	2.3	1.2	1.3	1.6	1.6	0.4	1.2	2.3
MAGNESIUM	0.08	0.04	0.09	0.07	0.1	0.0	0.04	0.09
SODIUM	113	106	109	109	109.3	2.5	106	113
POTASSIUM	2.6	2.4	2.4	2.3	2.4	0.1	2.3	2.6
CARBONATE	19	19	26	26	22.5	3.5	19	26
BICARBONATE	211	207	195	193	201.5	7.7	193	211
SULFATE	36	36	34	35	35.3	0.8	34	36
CHLORIDE	3.4	2.9	3	4.6	3.5	0.7	2.9	4.6
NITRATE	0.02	<.01	<.01	0.02	0.0	0.0	0	0.02
FLUORIDE	0.25	0.25	0.23	0.23	0.2	0.0	0.23	0.25
SILICA	15	16	18	18	16.8	1.3	15	18
TDS	317	307	316	315	313.8	4.0	307	317
CONDUCTIVITY	477	467	471	467	470.5	4.1	467	477
ALKALINITY	205	202	204	202	203.3	1.3	202	205
PH	8.82	8.88	9.19	9.11	9.0	0.2	8.82	9.19
ARSENIC	<.001	<.001	0.001	0.001	0.0	0.0	0	0.001
BARIUM	0.05	0.04	0.04	0.04	0.0	0.0	0.04	0.05
CADMIUM	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
CHROMIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
IRON	0.02	0.1	0.03	0.01	0.0	0.0	0.01	0.1
LEAD	<.001	0.001	<.001	<.001	0.0	0.0	0	0.001
MANGANESE	0.01	<.01	<.01	<.01	0.0	0.0	0	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
NICKEL	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	<.001	<.001	0.001	0.001	0.0	0.0	0	0.001
VANADIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	0.01	<.01	0.0	0.0	0	0.01
BORON	0.02	<.01	0.04	0.03	0.0	0.0	0	0.04
AMMONIA	0.02	0.01	0.04	0.05	0.0	0.0	0.01	0.05
RADIUM 226	0.4	0.4	0.7	0.6	0.5	0.1	0.4	0.7

TABLE 2.3-9

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-7

PARAMETER	SUMMER 9-6-90	SPRING 5-22-91	FALL 10-22-91	WINTER 1-24-91	AVG.	STD.	MIN.	MAX
CALCIUM	2.2	0.07	0.07	1.3	0.9	0.9	0.07	2.2
MAGNESIUM	0.13	<.01	0.01	0.003	0.0	0.1	0	0.13
SODIUM	110	123	118	120	117.8	4.8	110	123
POTASSIUM	2.1	12	4.9	3.5	5.6	3.8	2.1	12
CARBONATE	14	127	76	32	62.3	43.7	14	127
BICARBONATE	224	54	118	200	149.0	67.5	54	224
SULFATE	38	21	35	39	33.3	7.2	21	39
CHLORIDE	1.8	2.9	3.6	3.6	3.0	0.7	1.8	3.6
NITRATE	0.26	0.21	0.08	0.06	0.2	0.1	0.06	0.26
FLUORIDE	0.39	0.52	0.62	0.49	0.5	0.1	0.39	0.62
SILICA	17	13	19	18	16.8	2.3	13	19
TDS	318	355	338	335	336.5	13.1	318	355
CONDUCTIVITY	490	605	529	504	532.0	44.4	490	605
ALKALINITY	208	256	223	218	226.3	18.0	208	256
PH	8.67	10.35	9.92	9.24	9.5	0.6	8.67	10.35
ARSENIC	<.001	0.001	0.002	0.001	0.0	0.0	0	0.002
BARIUM	0.03	0.01	0.01	0.02	0.0	0.0	0.01	0.03
CADMIUM	0.0003	0.0001	<.0001	<.0001	0.0	0.0	0	0.0003
CHROMIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	0.02	0.02	<.01	0.0	0.0	0	0.02
IRON	0.01	0.21	0.12	0.01	0.1	0.1	0.01	0.21
LEAD	<.001	0.002	0.002	<.001	0.0	0.0	0	0.002
MANGANESE	0.01	<.01	<.01	<.01	0.0	0.0	0	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	<.01	0.01	0.01	<.01	0.0	0.0	0	0.01
NICKEL	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	0.001	0.001	0.001	<.001	0.0	0.0	0	0.001
VANADIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	<.01	<.01	0.0	0.0	0	0
BORON	0.07	0.05	0.06	0.04	0.1	0.0	0.04	0.07
AMMONIA	<.01	0.31	0.18	0.04	0.1	0.1	0	0.31
RADIUM 226	0.5	0.2	0.6	0.1	0.4	0.2	0.1	0.6

TABLE 2.3-10

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-8

PARAMETER	SUMMER 8-20-90	SPRING 5-22-91	FALL 10-22-91	WINTER 1-22-92	AVG.	STD.	MIN.	MAX
CALCIUM	2.7	2.7	2	2.6	2.5	0.3	2	2.7
MAGNESIUM	0.12	0.15	0.18	0.15	0.2	0.0	0.12	0.18
SODIUM	118	110	107	112	111.8	4.0	107	118
POTASSIUM	2	2.3	2.3	2.1	2.2	0.1	2	2.3
CARBONATE	41	19	18	19	24.3	9.7	18	41
BICARBONATE	184	210	214	211	204.8	12.1	184	214
SULFATE	47	34	34	35	37.5	5.5	34	47
CHLORIDE	3.2	3.3	3.5	3.8	3.5	0.2	3.2	3.8
NITRATE	0.03	0.05	<.01	<.01	0.0	0.0	0	0.05
FLUORIDE	0.31	0.29	0.25	0.27	0.3	0.0	0.25	0.31
SILICA	13	15	18	18	16.0	2.1	13	18
TDS	339	312	313	323	321.8	10.8	312	339
CONDUCTIVITY	529	471	463	470	483.3	26.6	463	529
ALKALINITY	219	204	205	205	208.3	6.2	204	219
PH	9.34	8.91	8.97	8.9	9.0	0.2	8.9	9.34
ARSENIC	<.001	<.001	<.001	<.001	0.0	0.0	0	0
BARIUM	0.03	0.09	0.07	0.07	0.1	0.0	0.03	0.09
CADMIUM	0.0002	<.0001	<.0001	<.0001	0.0	0.0	0	0.0002
CHROMIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
IRON	0.06	0.05	0.05	0.04	0.0	0.0	0.04	0.06
LEAD	0.002	0.001	0.001	<.001	0.0	0.0	0	0.002
MANGANESE	0.01	0.02	0.01	0.01	0.0	0.0	0.01	0.02
MERCURY	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	0.02	<.01	<.01	<.01	0.0	0.0	0	0.02
NICKEL	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	0.006	0.006	0.002	0.002	0.0	0.0	0.002	0.006
VANADIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	<.01	<.01	0.0	0.0	0	0
BORON	0.07	0.05	0.05	0.03	0.1	0.0	0.03	0.07
AMMONIA	<.01	0.03	<.01	0.01	0.0	0.0	0	0.03
RADIUM 226	0.6	0.9	0.9	0.8	0.8	0.1	0.6	0.9

TABLE 2.3-11

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-9 (RECAPTURE FM.)

PARAMETER	SUMMER 8-16-90	SUMMER 9-6-90	SPRING 5-22-91	FALL 10-22-91	WINTER 1-21-92	AVG.	STD.	MIN.	MAX
CALCIUM	2.4	1.8	1.1	1.3	4.3	2.2	1.2	1.1	4.3
MAGNESIUM	0.15	0.1	0.02	0.04	0.3	0.1	0.1	0.02	0.3
SODIUM	108	143	152	147	153	140.6	16.7	108	153
POTASSIUM	2	1.9	9.7	2.7	27	8.7	9.6	1.9	27
CARBONATE	11	41	76	30	40	39.6	21.2	11	76
BICARBONATE	231	193	151	216	194	197.0	27.0	151	231
SULFATE	35	67	56	61	62	56.2	11.2	35	67
CHLORIDE	2.5	19	20	20	53	22.9	16.5	2.5	53
NITRATE	0.02	0.01	0.03	0.12	0.03	0.0	0.0	0.01	0.12
FLUORIDE	0.26	0.36	0.36	0.31	0.33	0.3	0.0	0.26	0.36
SILICA	18	6	13	20	19	15.2	5.2	6	20
TDS	318	408	433	421	487	413.4	54.8	318	487
CONDUCTIVITY	471	640	687	627	760	637.0	95.2	471	760
ALKALINITY	207	226	250	227	225	227.0	13.7	207	250
PH	8.8	9.31	9.76	9.23	9.21	9.3	0.3	8.8	9.76
ARSENIC	<.001	<.001	<.001	0.002	0.002	0.0	0.0	0	0.002
BARIUM	0.03	0.02	0.03	0.06	0.03	0.0	0.0	0.02	0.06
CADMIUM	0.0001	<0.0001	0.0001	<.0001	<.0001	0.0	0.0	0	0.0001
CHROMIUM	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	<.01	<.01	<.01	0.01	0.0	0.0	0	0.01
IRON	0.04	<.01	0.04	0.03	0.04	0.0	0.0	0	0.04
LEAD	<.001	<.001	0.001	0.002	0.078	0.0	0.0	0	0.078
MANGANESE	0.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	<.01	0.01	0.01	0.01	<.01	0.0	0.0	0	0.01
NICKEL	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	0.002	<.001	<.001	0.002	<.001	0.0	0.0	0	0.002
VANADIUM	<.01	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	<.01	0.03	0.01	0.0	0.0	0	0.03
BORON	0.03	0.08	0.03	0.07	0.05	0.1	0.0	0.03	0.08
AMMONIA	<.01	<.01	<.01	0.01	0.03	0.0	0.0	0	0.03
RADIUM 226	0.4	0.1	0.2	0.6	0.4	0.3	0.2	0.1	0.6

TABLE 2.3-12

HYDRO RESOURCES INC.  
CROWNPOINT PROJECT  
WATER QUALITY SUMMARY  
WELL CP-10(DAKOTA FM.)

PARAMETER	SPRING 5-22-91	SUMMER 8-5-91	FALL 10-22-91	WINTER 1-22-92	AVG.	STD.	MIN.	MAX
CALCIUM	2.1	1.9	1.9	2.2	2.0	0.1	1.9	2.2
MAGNESIUM	0.15	0.11	0.17	0.11	0.1	0.0	0.11	0.17
SODIUM	229	217	231	224	225.3	5.4	217	231
POTASSIUM	3.8	2	1.5	2.5	2.5	0.9	1.5	3.8
CARBONATE	46	16	34	58	38.5	15.5	16	58
BICARBONATE	214	243	210	161	207.0	29.5	161	243
SULFATE	227	251	251	250	244.8	10.3	227	251
CHLORIDE	3.9	9.6	5.3	5	6.0	2.2	3.9	9.6
NITRATE	<.01	0.01	0.04	0.24	0.1	0.1	0	0.24
FLUORIDE	0.72	0.57	0.55	0.6	0.6	0.1	0.55	0.72
SILICA	3	14	17	18	13.0	6.0	3	18
TDS	671	679	688	693	682.8	8.4	671	693
CONDUCTIVITY	1000	981	988	996	991.3	7.3	981	1000
ALKALINITY	251	225	228	228	233.0	10.5	225	251
PH	9.31	8.81	9.07	8.97	9.0	0.2	8.81	9.31
ARSENIC	<.001	<.001	<.001	<.001	0.0	0.0	0	0
BARIUM	0.02	0.01	0.05	0.01	0.0	0.0	0.01	0.05
CADMIUM	<0.0001	<0.0001	<0.0001	<0.0001	0.0	0.0	0	0
CHROMIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
COPPER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
IRON	<.01	0.13	0.06	0.09	0.1	0.0	0	0.13
LEAD	<.001	<.001	0.004	<.001	0.0	0.0	0	0.004
MANGANESE	0.01	0.01	0.01	0.01	0.0	0.0	0.01	0.01
MERCURY	<.0001	<.0001	<.0001	<.0001	0.0	0.0	0	0
MOLYBDENUM	0.01	0.01	<.01	<.01	0.0	0.0	0	0.01
NICKEL	<.01	<.01	<.01	<.01	0.0	0.0	0	0
SELENIUM	<.001	<.001	<.001	<.001	0.0	0.0	0	0
SILVER	<.01	<.01	<.01	<.01	0.0	0.0	0	0
URANIUM	<.001	<.001	<.001	<.001	0.0	0.0	0	0
VANADIUM	<.01	<.01	<.01	<.01	0.0	0.0	0	0
ZINC	<.01	<.01	<.01	<.01	0.0	0.0	0	0
BORON	0.17	0.14	0.2	0.2	0.2	0.0	0.14	0.2
AMMONIA	0.08	0.03	0.03	0.05	0.0	0.0	0.03	0.08
RADIUM 226	0.5	0.6	0.4	0.9	0.6	0.2	0.4	0.9

TABLE 2.3-13

HYDRO RESOURCES INC.  
 CROWNPOINT PROJECT  
 WATER QUALITY SUMMARY  
 WESTWATER AVERAGE (CP2, CP3, CP5, CP6, CP7, CP8)

PARAMETER

CALCIUM	25
MAGNESIUM	2
SODIUM	147
POTASSIUM	147
CARBONATE	20
BICARBONATE	202
SULFATE	64
CHLORIDE	214
NITRATE	0.04
FLUORIDE	0.40
SILICA	17
TDS	773
CONDUCTIVITY	1,272
ALKALINITY	199
PH	8.77
ARSENIC	0.000
BARIUM	0.11
CADMIUM	0.0000
CHROMIUM	0.00
COPPER	0.00
IRON	0.22
LEAD	0.000
MANGANESE	0.04
MERCURY	0.0000
MOLYBDENUM	0.00
NICKEL	0.00
SELENIUM	0.000
SILVER	0.00
URANIUM	0.005
VANADIUM	0.00
ZINC	0.00
BORON	0.05
AMMONIA	0.07
RADIUM 226	22.20

the NRC license. A written report will be prepared by the SERP which evaluates safety, and environmental concerns, and demonstrates compliance with applicable NRC license requirements. The written SERP report will be maintained at the site.

The Mine Unit Hydrologic Test Document contains the following:

- a. a description of the proposed mine unit (location, extent, etc.);
- b. a map(s) showing the locations of the baseline mining wells, and all monitor wells;
- c. geologic cross-sections, and cross section location maps.
- d. isopach map of the overlying confining unit.
- e. discussion of how the hydrologic test was performed, including well completion reports;
- f. discussion of the results, and conclusions of the hydrologic test including raw data for the pumping test(s), drawdown match curves, potentiometric surface maps, water level graphs, drawdown maps, and when appropriate, directional transmissivity data, and graphs;
- g. sufficient information to show that wells in the monitor well ring will be in adequate communication with the production patterns;
- h. any other information pertinent to the area tested will be included, and discussed;

After appropriate review of Mine Unit Hydrologic Test Document, and subsequent authorization by the SERP, injection of lixiviant will begin in the new mining unit.

## 8.6 Baseline Water Quality Determination

### 8.6.1 General

The collection of baseline water quality data, and determination of baseline water quality conditions is very important as the Upper Control Limits (UCL's), and ground water restoration objectives are based on this data.

COP-84



March 1, 2005

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judges:

E. Roy Hawkens, Presiding Officer  
Dr. Richard F. Cole, Special Assistant  
Dr. Robin Brett, Special Assistant

In the Matter of:

HYDRO RESOURCES, INC.

P.O. Box 777

Crownpoint, New Mexico 87313

Docket No. 40-8968-ML

ASLBP No. 95-706-01-ML

DECLARATION OF MICHAEL G. WALLACE

I, Michael G. Wallace, do hereby swear that the following is true to the best of my knowledge. I am qualified and competent to give this declaration, and the factual statements herein are true and correct to the best of my knowledge, information and belief. The opinions expressed herein are based on my best professional judgment.

Name and Qualifications

1. My name is Michael G. Wallace. My education and experience as a professional hydrologist are described in my vita, attached to this testimony as Exhibit A. I have a master's degree in hydrology from the University of Arizona and I have extensive knowledge and experience in the movement of contaminants in groundwater systems, as a consultant to industry and government agencies. As a consultant, I help to define a given problem by evaluating

1



existing geologic and hydrologic knowledge and data and developing additional important data and knowledge through hydrologic techniques. This is part of developing a hydrogeologic conceptual model. My experience includes development of such models and the application of those to the valid prediction of contaminant transport through numerical modeling.

2. For much of the past 19 years, I have supported development of conceptual and numerical models to assess hydrologic performance of several proposed and active national and international radioactive waste geologic repositories. This experience, which is highly relevant to the case at hand, has qualified me in several areas of advanced hydrogeologic work, including:

- Groundwater well pump test analyses and interpretation.
- Geostatistical interpretation of aquifer variability. Currently I am supporting a U.S. national laboratory in the qualification of an advanced code, called nSIGHTS, which merges aquifer test results with geostatistical analysis, explicitly acknowledging the range of plausible variations in the interpretation of hydrologic data.
- Analysis of interconnections between stacked aquifers.
- Analysis of contaminant transport modeling results.
- One dimensional ("1D"), two dimensional ("2D") and three dimensional ("3D") groundwater flow and contaminant transport modeling for homogeneous (scoping) and heterogeneous cases.
- Calibration and validation of groundwater flow and transport models. The models mentioned above cannot give trusted or believable predictions if they cannot match the results of pump tests or other observations specific to the aquifer that is being modeled. Testing the model against these pump tests and observations is called calibration and validation.

- Analysis of multi-rate and multi-porosity contaminant diffusion in aquifers. Different pollutants can move at different rates through an aquifer, partly as a function of their rock-interaction properties.
- Analysis of mine-induced subsidence upon aquifer transmissivities and subsequent solute transport.

3. I continue to perform many of these tasks, particularly for Sandia National Laboratories (“SNL”) and the U.S. Department of Energy (“DOE”) in the ongoing permitting effort for the Yucca Mountain Project (“YMP”) high-level nuclear waste underground repository and the Waste Isolation Pilot Plant (“WIPP”). I most recently contributed as the lead project reviewer of a 3D heterogeneous groundwater flow model of the Yucca Mountain multi-aquifer system developed at Los Alamos National Laboratory (“LANL”) and based on a regional model developed by the U.S. Geological Survey (USGS). This scientific work is ultimately reviewed by the NRC.

#### Purpose of Testimony

4. I have been retained by ENDAUM and SRIC as an expert in the field of groundwater hydrology in the matter of the application for a source and byproducts materials license submitted by Hydro Resources, Inc. (“HRI”) for the Crownpoint Uranium Solution Mining Project (“CUP”), Crownpoint and Church Rock, McKinley County, Navajo Nation, New Mexico.

#### Materials Reviewed

5. In preparing this declaration, I reviewed published geologic, hydrologic and hydrogeologic literature on the Church Rock and Crownpoint areas; re-reviewed relevant portions of the Nuclear Regulatory Commission’s (“NRC’s”) Final Environmental Impact

Statement ("FEIS"), Safety Evaluation Report ("SER"), and License SUA-1508 for the CUP; reviewed affidavits and testimony I have given previously in this proceeding since 1997; and reviewed numerous documents in the Hearing Record, including several of HRI's responses to the NRC Staff's Request for Additional Information ("RAI") and major portions of HRI's environmental reports for the Church Rock, Unit I and Crownpoint sites. Literature and documents that I cite in this declaration are listed below.

Anderson, O.J, and S.G. Lucas, 1996. "The Base of the Morrison Formation (Upper Jurassic) of Northwestern New Mexico and Adjacent Areas", from *The Continental Jurassic*, Michael Morales, ed., 1996. Museum of Northern Arizona Bulletin 60.

Bartels, C. S. (HRI), 1997. Letter to W. H. Ford, NRC, re: HRI response to NRC Q99: Sensitivity Analysis of Modeled Unit [sic] Site Ground-Water Flow, August 18. Listed in but missing from NB 10.3, ACN 970108219.

Bartels, C. S., 1999. Affidavit (February 19), attached as third exhibit to Hydro Resources, Inc.'s Response to Intervenors' Brief in Opposition to Hydro Resources, Inc.'s Application for a Materials License with Respect to Groundwater Issues, February 19.

Cowan, E. J, 1991, "The Large-Scale Architecture of the Fluvial Westwater Canyon Member, Morrison Formation (Upper Jurassic), San Juan Basin, New Mexico" In: Miall, A.D. & Tyler, N. (eds) (1991), "The three-dimensional facies architecture of terrigenous clastic sediments and its implications for hydrocarbon discovery and recovery". *SEPM Concepts in Sedimentology and Paleontology*, 3, pp. 80-93.

Freeze, R.A. and J. Cherry, 1979. *Groundwater*, Prentice Hall pubs.

Galloway, W.E., 1980, "Deposition and Early Hydrologic Evolution of Westwater Canyon Wet Alluvial-Fan System," New Mexico Bureau of Mines and Mineral Resources, Memoir 38.

Geraghty & Miller, Inc., 1993. "Analysis of Hydrodynamic Control, HRI, Inc. Crownpoint and Churchrock New Mexico Uranium Mines." Prepared for HRI, Inc., by Geraghty & Miller (Corpus Christi, Tex.), October 7. NB 6.7, ACN 9312160178.

Hilpert, L.S., 1969. *Uranium Resources of Northwestern New Mexico*. U.S. Geological Survey Professional Paper 603.

Hydro Resources, Inc., 1988. Application for Source Materials License (Hearing Record No. 8805200339) and Churchrock Project Environmental Report, April 13. NB 2, ACN 8805200334 and 8805200346.

- Hydro Resources, Inc., 1992a. Pump Test Analysis, Crownpoint Project, April 1991, February; Attachment 82-1 to HRI's Response to NRC Request for Additional Information No. 82, attached to HRI 1996a, NB 9.1, ACN 9604030208 (see, reference below).
- Hydro Resources, Inc., 1992b. Crownpoint Project In-Situ Mining Technical Report, letter of transmittal dated July 31; cover of report dated June 12. NB 5.1, ACN 9509080094.
- Hydro Resources, Inc., 1993a. Revised Church Rock Environmental Report, March 16. NB 6.1, ACN 9304130415; NB 6.2, ACN 9304130421.
- Hydro Resources, Inc., 1993b. Revised Church Rock Environmental Report, October 11. NB 6.7, ACN 9312140083 (cover memo from M. S. Pelizza) and ACN 9312140087 (revised pages).
- Hydro Resources, Inc., 1996a. Responses to NRC Requests for Additional Information on Water Resources, RAI 49-91, April 1. NB 9.1; ACN 9604030208. Specific responses by HRI to NRC's RAIs that are referenced in this declaration and in the exhibits attached hereto are:
- RAI #50 — Degradation of Crownpoint Water Supply Wells By Restored Solution Mine Ground Water
  - RAI #54 — Potentiometric Surface Map and Ground-Water Flow Velocities for the Westwater Aquifer
  - RAI #77 — Model of Hydrodynamic Control Crownpoint Property
  - RAI #81 — Pump Test and Pre-pump Test Water Levels May Not Indicate the Dakota Sandstone is Hydraulically Isolated
  - RAI #82 — Corrections in Water Level for Barometric Efficiency
  - RAI #84 — Modeling Effect of Town Wells on Pump Test
  - RAI #99 — Sensitivity Analysis of Modeled Unit 1 Site Ground-Water Flow
- Hydro Resources, Inc., 1996b. Underground Injection Control (UIC) Permit Application, Unit 1, Crownpoint Uranium Project. Submitted to USEPA Region IX, November 12.
- Hydro Resources, Inc., 1997b. Crownpoint Uranium Project Consolidated Operations Plan, Revision 2.0. Albuquerque, New Mexico, August 15, 1997. NB 10.3, ACN 9708210179.
- Hydro Resources, Inc., 1997a. Crownpoint Uranium Project Consolidated Operations Plan, Revision 1.0, Albuquerque, New Mexico, May 15, 1997. NB 10.2, ACN 9705220214.
- McDonald, M.G. and A.W. Harbaugh, 1988, A modular three-dimensional finite-difference ground-water flow model, U.S. Geological Survey, TWRI.
- Peterson, R.J., 1980. "Geology of Pre-Dakota Uranium Geochemical Cell, Sec. 13, T.16N, R.17W, Church Rock Area, McKinley County". From *Geology and mineral technology*

*of the Grants uranium region 1979*, C. A. Rautman, ed., New Mexico Bureau of Mines and Mineral Resources, Memoir 38, 131-138.

Thomas A. Prickett & Associates, 1983. Analysis of South Trend Development Area Pumping Test, August 16-18, 1982, Crownpoint, McKinley County, New Mexico. Appendix A to Hydro Resources, Inc., Environmental Assessment, Unit 1 Allotted Lease Program, Eastern Navajo District, New Mexico, January 6, 1992. NB 5.0 and 5.1; ACN 9509080065; also attached to HRI's April 5, 1996, letter to NRC in NB 9.2, ACN 9604090313.

United Nuclear Corporation, 2003. Northeast Church Site Assessment, prepared by MWH (Steamboat Springs, Colorado), July.

U.S. Nuclear Regulatory Commission, 2003. Yucca Mountain Review Plan. NUREG 1804, Final Rev. 2. Prepared by Center for Nuclear Waste Regulatory Analyses for U.S. Nuclear Regulatory Commission. (A pdf version of this document can be accessed at [http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1804/.](http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1804/))

U.S. Nuclear Regulatory Commission, 1998. Source Materials License SUA-1508 (and Attachment A thereto), Hydro Resources, Inc., Crownpoint Uranium Project, January 5, 1998. NB 11, ACN 980116066.

U.S. Nuclear Regulatory Commission, 1997b. Safety Evaluation Report, Hydro Resources, Inc., License Application for Crownpoint Uranium Solution Mining Project, McKinley County, New Mexico. Washington, D.C., December 5, 1997. NB 10.4, ACN 9712310298.

U.S. Nuclear Regulatory Commission, 1997a. *Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico*, NUREG-1508, BLM NM-010-93-02, BIA EIS-92-001. USNRC, Office of Nuclear Material Safety and Safeguards, in cooperation with U.S. Bureau of Land Management and U.S. Bureau of Indian Affairs, February 1997. NB 10, ACN 9703200270.

U.S. Nuclear Regulatory Commission, 1996. Memo to Hydro Resources, Inc. Subject: Request for Additional Information; Water Resources Protection and Cost/Benefit Analysis; Safety Analysis Review and Environmental Review for the Hydro Resources, Inc. (HRI) Uranium Solution Mining License Application, Crownpoint, New Mexico, February 9. NB 9, ACN 9602140148.

Wallace, M.G., 1999a. Written Testimony, January 8; attached as Exhibit 3 (Volume IV) to Intervenor's Amended Written Presentation in Opposition to Hydro Resources, Inc.'s Application for a Materials License with Respect to: Groundwater Protection, January 18.

Wallace, M.G., 1999b. Written Reply Testimony, attached as Exhibit C to ENDAUM'S and SRIC'S Reply in Response to HRI's and the NRC Staff's Response Presentations on Groundwater Protection Issues, April 8.

Wallace, M.G., 1999c. Response Affidavit, attached as Exhibit 2 to Intervenors' Joint Response to HRI's and the NRC Staff's Responses to the Presiding Officer's April 21, 1999 Memorandum and Order (Questions), May 25.

Webb, E., 1994. "Simulating the Three-Dimensional Distribution of Sediment Units in Braided-Stream Deposits", *Journal of Sedimentary Research*, vol. B64, no. 2, 1994, 219-231.

Wentworth, D.W., Porter, D.A., Jensen, H.N., 1980. Geology of Crownpoint Sec. 29 Uranium Deposit, McKinley County. In: *Geology and Mineral Technology of the Grants Uranium Region, 1979*, compiled by Christopher A. Rautman. New Mexico Bureau of Mines and Mineral Resources, Memoir 38.

Zheng, C., 1990. MT3D: A modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in ground-water systems. U.S. Environmental Protection Agency, R.S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

6. In addition to my extensive literature review, I also conducted original groundwater flow and contaminant transport modeling for the Crownpoint and Unit I mining sites, and calculated travel times for contaminant transport between the Section 17 mine and the planned Springstead Estates housing development in Church Rock Chapter. The methods and results of my work are described in detail in the Analysis sections of this declaration.

#### Summary of Conclusions

7. This declaration evaluates assertions and claims in the FEIS, in other parts of HRI's application, and in the Hearing Record that ISL mining will not degrade groundwater at HRI's Crownpoint, Unit 1, and Section 17 proposed mining sites. I note that the FEIS does not discriminate between Section 17 and Section 8, but instead lumps them into a "Churchrock" site. For the purposes of this declaration, my comments on the Churchrock site can be considered to apply only to Section 17, unless otherwise stated.

8. With respect to the Crownpoint site, my analysis demonstrates that the groundwater transport model employed by HRI is uncalibrated and indefensible, especially in light of HRI's own field data. My alternate model shows a superior calibration to HRI's field data, and it predicts that even during mining, contaminated mining fluids can reach the Crownpoint municipal water supply wells in as little as seven years. I also describe how HRI's 1991 pump test was conducted improperly, which the licensee has relied upon to assert that the overlying Dakota aquifer will not be contaminated by ISL mining operations. I have considered new information, which strongly suggests an increasing hydraulic connection between the Dakota and the mining zone along a trend from the west end of the mining area to the east end.

9. For the Unit 1 site, I prepared and executed a groundwater model that also shows a better calibration than HRI's model, and I use that model to predict possible contamination of the Crownpoint municipal water supply wells resulting from mining at the Unit I site. According to this model, the water supply wells could start to become contaminated in as little as 63 years from the initiation of mining.

10. My testimony on the Section 17 site describes the serious deficiencies in HRI's hydrogeologic conceptual model and aquifer pump tests that led HRI to assert incorrectly that the mining zone is confined from overlying and underlying fresh water aquifers. I also present a plausible, conservative scenario in which contaminated ISL water will be pulled into water supply wells, which will have to be drilled at the planned Springstead Estates Housing Development, in as little as 150 years.

11. Finally, I conclude that License Conditions 10.23 and 10.31 of SUA-1508 will not remove judgment on the part of the licensee from *post-licensing* aquifer characterization studies that HRI has performed poorly and misinterpreted in the past. For these reasons, I recommend

that aquifer characterization take place before the adjudication of License SUA-1508 is concluded, or the license issued to HRI on January 5, 1998, be revoked.

**I. Crownpoint Site: Independent Modeling of Contaminant Transport Demonstrates ISL Mining Will Result in Rapid Contamination of Crownpoint's Municipal Water Supply Wells.**

**A. The HRI model of groundwater flow and transport is uncalibrated and indefensible.**

12. The HRI Crownpoint and Unit 1 groundwater flow and transport model, which appears in the FEIS at 3-28 and is reproduced in **Exhibit B, Figure 1**, attached hereto, presents a benign prediction of complete mining fluid containment throughout the mining operation lifetime and well beyond. This has been asserted in spite of the fact that the ore zone to be mined is as little as 2,000 feet from a major water supply well in the same aquifer, with no natural barriers between. In fact, this water supply well, NTUA-1, is approximately as close to the ore zone as the ore zone is to the land surface.

13. The model that is HRI's basis for this prediction assumes, incorrectly, that the aquifer is essentially a giant sandbox, having little or no channeling features. This assumption is indefensible on several grounds. First, and most important, it is at odds with HRI's own aquifer pump test results, which I describe in detail later in this declaration. Second, it is inconsistent with the widely held consensus among scientists, as represented in the published literature (see, e.g., Cowan 1991, Galloway 1980, Peterson 1980, Wentworth 1980), that the Westwater Canyon Member is characterized by a channel-like geologic fabric. (Also see Dr. Richard Abitz's and Dr. Spencer Lucas's current declarations in this phase of the proceeding; they contain more extensive references and discussion on the subsurface geology at the Section 17, Unit 1 and

Crownpoint sites).<sup>1</sup> This channelization appears to be oriented directly from the ore zone to the water supply wells. The fact of channelization and its apparent orientation towards the municipal wells leads to the potential for extremely rapid contamination of those wells, as this declaration describes. And third, it is based on a faulty, uncalibrated groundwater model.

14. Calibration is important because, at a very minimum, any model of the aquifer should first be able to accurately simulate the known water level fluctuations (also referred to as a potentiometric surface) at a representative sampling of observation wells before it can be used as a predictive tool for contaminant transport. Model calibration consists largely of developing a single, comprehensive, and accurate simulation of the history of water level fluctuations as measured in monitor wells. Some of these fluctuations are caused by natural or outside events, such as the impacts of nearby municipal pumping wells, for example. Other fluctuations are deliberately induced through pump testing in order to interrogate the aquifer system on a more local scale. In pump tests, generally, a single well is pumped, while the water level fluctuations are monitored in surrounding observation wells. The resulting behavior of the system is influenced not only by the pumping rate, but also by several other variables, including the type and nature of rock or alluvium that the water flows through. Figures 2, 3 and 4 in Exhibit B provide a general description of such pump tests and some of the basic features and parameters that control the results.

15. The NRC Staff is clearly aware of the importance of calibration, as documented in HRI's response to the Staff's RAI #84 (HRI, 1996a). There, the NRC required HRI to provide,

---

<sup>1</sup> References to the stream-like nature of aquifer sediments are not hard to find, as this type of condition is more the rule than the exception. For example, the paper published in the *Journal of Sedimentary Research* by Eric Webb (1994) states, "Full hydrogeologic characterization of a sediment body must include a detailed description of its three-dimensional internal geometry.... A computer code ... was developed that simulates the three-dimensional internal geometry of sediment units for braided stream deposits..." To my knowledge, HRI has never developed a 3D picture of the subsurface geology at any of the three proposed mining sites.

among other things, calibration data (“how good a match was achieved”) and a complete accounting of all the wells that were used in the history matching for the model that was used to create Figure 3.10 in the FEIS (at 3-28). That is the figure and model that is used by HRI to justify its findings of slow contaminant transport times from the Crownpoint and Unit 1 sites to the Crownpoint municipal wells.

16. HRI did not comply with the Staff’s request. Rather, in its response to RAI #84 (HRI, 1996a), HRI produced a series of simplistic computer runs, wherein each run was “calibrated” to a single observation well drawdown history. The five runs produced five different “calibrated” models, as summarized in the Crownpoint Project In Situ Mining Technical Report (HRI, 1992b, Table 6) and in HRI’s response to RAI #84 (HRI, 1996a). But none of those models were used for the transport simulation and none of those models were calibrated against the drawdown histories of all of the test observation wells. It is generally quite easy to match a model to a single observation well history, so long as you ignore all of the other equally important information from the other wells. It is also generally a meaningless exercise because it does not match a representative sampling of known data.

17. Instead, HRI chose an average value of certain aquifer parameters from this collection of models. These parameters were then fed into the model that was the source for HRI’s travel time predictions (see, HRI Response to RAI #84 and FEIS, Figure 3.10 at 3-28). For the purposes of this Declaration, I will call that final model the “HRI model.”

18. Taking the averages of those values and running a new model from the averages provides no predictive value, unless that model has a good calibration. In other words, using averages may, in limited circumstances, have predictive value if the new model demonstrates a good history match to ALL observation well drawdown histories simultaneously (or at least to a

representative sample that covers the area of concern). HRI has not presented the history match of its single transport model to ANY observation well drawdown histories. As I describe below, I have recreated HRI's model to demonstrate the poor calibration that the licensee never documented.

19. In support of this declaration, I developed a contaminant transport model that more closely follows the procedures adhered to by professional hydrologists because it is more closely calibrated to HRI's pump test data than HRI's model. The following text covers the new models I developed, and shows how they compare with HRI's uncalibrated modeling in explaining the hydrology of the area and in predicting contaminant transport.

20. I modeled contaminant transport from the Crownpoint mining site to the Crownpoint municipal wells in two ways: (1) using HRI's assumption that the Westwater Aquifer is a homogeneous sandstone, and (2) as it should have been modeled using HRI's own site-specific field data — as heterogeneous, fluvial, interbedded and braided sandstone. The heterogeneous case I performed consists of the only calibrated model ever created for the Crownpoint site<sup>2</sup>. As such, it is the most reliable predictor of consequences of the proposed mining activity, with respect to possible groundwater contamination outcomes. This model shows contamination reaching the nearest public water supply well in as little as seven years, even while mining is still occurring and active groundwater monitoring is in place. This rapid travel time is about 25 times faster than that predicted by HRI's uncalibrated, homogeneous aquifer model.

---

<sup>2</sup> The NRC Staff was incorrect when it stated in the FEIS (at 3-25) that, "A potentiometric surface map of the Westwater aquifer for the Unit 1 and Crownpoint sites was prepared using a calibrated flow model to match monitor well level data collected in the summer of 1992 (Figure 3.10)." As described earlier, no such calibration evidence exists in the record. For the reasons explained above, HRI's model was not calibrated.

21. The compact disk ("CD") contained in **Exhibit C** attached hereto and labeled "Simulated Contamination of Crownpoint Water Supply Wells from Proposed Uranium ISL Mining" is an annotated animation that summarizes many of the issues addressed in this section of my declaration. Review of that animation will aid in the study of my testimony. Some of the modeling and graphics in this CD are conceptual in nature, and although very similar, have been superceded by the modeling work and figures presented in this declaration.

22. The channel fabric that I have described is best represented by an explicit characterization of the aquifer as heterogeneous. Heterogeneous means that the rock tightness or resistance to water flow varies from one area to the next, or even one point to the next. Hydrologic maps of aquifer heterogeneity typically cover the changes in hydraulic conductivity, designated by hydrologists as "K", over the extent of the aquifer. The higher the K, the faster that water can move through the rock. Since K can typically vary over several orders of magnitude, groundwater velocities can also vary in a similar way. In the event of buried, discontinuous channel features, this heterogeneous modeling method would be essential to properly characterize the groundwater system. In those systems, the channels could have much higher K values than the surrounding rock. An example of such a heterogeneous K map is shown for the Crownpoint site in **Exhibit B, Figure 5**. In this declaration, I also refer to parameters called "permeability" and "transmissivity." These are almost synonymous to K, having only minor variations in their technical definitions that do not affect my discussion materially.

23. Groundwater travel speed would likely be significantly greater in the heterogeneous case, particularly when compared with the homogeneous case. Homogeneous cases represent the aquifer rock as having uniform properties everywhere. In other words, there

would be no means to represent buried channels. As a rule, professional hydrologists use homogeneous cases only in limited circumstances, most often as scoping calculations, and not for full-fledged, serious model analyses which are intended to be used as a basis for a regulatory decision. An example of such a homogeneous K map is shown for the Crownpoint site in **Exhibit B, Figure 6.**

24. Another important concept in analyzing the predictive quality of a contaminant transport model is sensitivity studies. With regard to the HRI models, the Staff's RAI #99 (Bartels, 1997<sup>3</sup>) required HRI to conduct sensitivity analyses of their model results:

"The applicant must provide a sensitivity analysis of the Unit 1 site, and flow times from the Unit 1 site to the Town of Crownpoint wells as a function of variations in permeability, storage coefficient, aquifer thickness and porosity."

Sensitivity studies, such as those requested by the NRC, are commonplace in hydrologic modeling that predicts contaminant flow. They are designed to examine important parameters and conceptions built into the model, which are not well understood. Such sensitivity studies and related uncertainty analyses are widely accepted as fundamental to proper hydrologic practice, and in my experience, have been essential to groundwater activity that the NRC has regulated at other projects.

25. Typically in a sensitivity study, the input parameters to a base model are varied, in a realistic way, to produce alternative models. Those alternatives are then compared to the base case. If the alternatives are equally plausible (and calibrated), but show a more conservative result (faster travel times, for example), then it is customary (as recommended in NUREG-1804 [USNRC, 2003]), to replace the base case with a more conservative sensitivity run.

---

<sup>3</sup> NRC's original RAI#99 could not be located in the Hearing File. Hence, the Staff's request was taken from HRI's response, which was contained in a letter from C. S. Bartels to W. H. Ford, August 18, 1997.

26. The “variations in permeability” requested by the Staff in RAI #99 most certainly includes exploration of variations in the hydraulic conductivity throughout the model area.<sup>4</sup> In other words, the comment required the applicant to address the issue of heterogeneity through an alternative model. Again, **Figure 5 in Exhibit B** shows the sort of alternative conceptual model that treats “variations in permeability” as a serious investigation. However, HRI produced a simplistic sensitivity analysis that for all cases continued to treat the aquifer as homogeneous at both the Unit 1 and the Crownpoint sites.

27. Sensitivity studies are only concerned with plausible model outcomes. The predictions of the models must be believable, and must not contradict known facts or knowledge. The effort to create model results, which match site conditions and field measurements, is known as calibration. In a calibration process, model simulations are repeatedly run, with varied parameter input values, until a good match to field data (called “history matching”) is achieved. If the model is based on poor interpretation of the underlying hydrogeologic conditions, then calibration will almost always fail.

28. Perhaps the most important factor in creating a contaminant transport model is conducting pump tests and matching those pump test results through effective calibration. A pump test involves a pumping well, which pumps water from the aquifer, and a series of monitoring wells, generally set in the same aquifer, which monitors the water levels in the aquifer as the pumping well is pumping (**Exhibit B, Figures 2 through 4**). By plotting the drop in water levels, known as drawdown, in the monitor wells during the pumping period, a “cone of depression” can be visualized, and important information can be interpreted about the aquifer. Contour maps can be drawn of the magnitude of water drop in the monitor wells at any particular

---

<sup>4</sup> As noted above, permeability, hydraulic conductivity, and transmissivity are synonymous for this discussion.

point in time, as shown in **Exhibit B, Figure 7**. In a simplified, ideal homogeneous aquifer, the contours would look perfectly circular, as **Figure 7** illustrates.

29. In its reply to RAI #99 (Bartels, 1997), HRI correctly stated that a drawdown cone of depression around a pumping well can be examined for evidence of variations from the ideal homogeneous isotropic aquifer conditions that they purport to exist there. That is achieved by determining whether or not the drawdown contours are close to perfectly circular. If they are, then the rock through which the groundwater moves is identical in all directions and all locations, and is devoid of any channeling features. If the drawdown cone is not perfectly circular, as suggested by **Exhibit B, Figure 8**, then the rock likely contains channeling features. The HRI model cannot recreate those pump test results because it treats the aquifer as if there were no channel-like features. The HRI pump test results are illustrated in **Exhibit B, Figure 10a**. CP-5, the pumping well during the 1991 pump test at the Crownpoint site, is shown at the center of the bull's eye pattern of drawdown contours. It was pumped at a fairly constant rate of 101.1 gallons per minute ("gpm") through the test period. The figure shows lines of equal drawdown resulting from the pump test at the very end of the 72-hour test, based on measurements of the monitor wells. The drawdown value represents how many feet the water level in each monitor well dropped from its original level by the end of the test. Clearly there is a trough pattern aligned slightly from the NW to the SE. That contrasts starkly with the idealized contour plot shown in **Exhibit B, Figure 7**.

30. In addition, HRI's response to RAI #82 (HRI, 1996a, Attachment 82-1) provides additional, compelling confirmation of this channelization. On page 26 of that response, the calculated angles of highest transmissivity, which correspond to the fastest flow path directions, range from -17 degrees to -27 degrees. This is shown in **Exhibit B, Figure 10b** of this

declaration as the two red arrows. Not surprisingly, they correspond almost exactly to the trough direction that I independently inferred. These calculations, which were performed by HRI, were not incorporated into any subsequent modeling. In that RAI #82 response, HRI asserted that the scale of the pump test was not suitable for incorporating such effects as heterogeneity into the model. That is inaccurate. Hydrologists routinely model systems with heterogeneity at scales both smaller and larger than the scale of their test. HRI apparently did not investigate this phenomenon any further, and in spite of this additional compelling field evidence of channeling — in a critical direction toward the town of Crownpoint water wells — the NRC staff did not require any further modeling work or modifications.

B. Comparison of homogeneous and heterogeneous contaminant flow models.

31. Models are attempts to capture enough of reality to develop plausible and reliable predictions. In this case, the model prediction is intended to be a conservative estimate of how long it would take for contaminated groundwater to reach the water supply well NTUA-1 from HRI's Crownpoint mining site. See, FEIS Fig. 3.9 at 3-23 and Fig. 3-10 at 3-28. In a manner consistent with NRC guidelines in NUREG-1804 (USNRC, 2003), I evaluated the HRI model in light of an alternative conceptual model, which is consistent with the available site-specific data. Table 1 details important assumptions, abstractions, and related results, of the three model sets considered. The first column represents the two HRI sets of model runs conducted in 1993 and 1996, using the AQUASIM code (HRI, 1996a, Attachment 77-1). The AQUASIM code does not have the ability to explicitly model contaminant transport.

32. Since calibration is critical to determining the relative plausibility of a model, that is, how well a model reflects the actual subsurface environment, I needed to compare the calibrations of the HRI models to my own heterogeneous model. Since HRI never directly

**Table 1. Characteristics of the Three Models Considered in Comparison Study**

	<b>1. HRI Transport Model</b>	<b>2. Homogeneous (Created by Wallace, and representative of extended HRI models)</b>	<b>3. ENDAUM Heterogeneous</b>
1	Crownpoint water supply wells pumping at constant rates: NTUA-1 27.7 gpm NTUA-2 58.7 gpm BIA-3 79.4 gpm BIA-5 6.2 gpm BIA-6 100.0 gpm	Crownpoint water supply wells pumping at constant rates: NTUA-1 27.7 gpm NTUA-2 58.7 gpm BIA-3 79.4 gpm BIA-5 6.2 gpm BIA-6 100.0 gpm	Crownpoint water supply wells pumping at constant rates: NTUA-1 27.7 gpm NTUA-2 58.7 gpm BIA-3 79.4 gpm BIA-5 6.2 gpm BIA-6 100.0 gpm
2	Aquifer is homogeneous, Therefore: Constant hydraulic conductivity (K) Constant permeability (k) See, Exhibit B, Figure 1	Aquifer is homogeneous, Therefore: Constant hydraulic conductivity (K) Constant permeability (k) See, Exhibit B, Figure 6	Aquifer is heterogeneous, consisting of a series of channel patterns angled from the ore zone towards the east, southeast. See, Exhibit B, Figure 5
3	K value not explicitly provided by HRI, but somewhere between 1.3 and 2 ft/day	K = 1.75 ft/day	K values vary by up to 3 orders of magnitude from .1ft/day and going up.
4	b= 200ft	b= 200ft	B= 200ft
5	Confined (no leakage)	Confined (no leakage)	Confined (no leakage)
6	Dispersivity not modeled	Dispersivity = 0 ft.	Dispersivity = 0 ft.
7	Concentration at mine area not modeled	Concentration at mine area = 100 mg/l	Concentration at mine area = 100 mg/l
8	Mining represented by scores of 5-spot patterns, covering over 500 acres. Net production flow up to 4000 gpm	Mining represented by a single 5-spot pattern covering roughly a sixth of the mine acreage. Net production flow of 40 gpm equals a hundredth of rate shown in 1 <sup>st</sup> column	Mining represented by a single 5-spot pattern covering roughly a sixth of the mine acreage. Net production flow of 40 gpm equals a hundredth of rate shown in 1 <sup>st</sup> column
9	Velocity ranges, in the area of concern from about 4 ft/year to 20 ft/year	Velocity ranges, in the area of concern from about 10 ft/year to 22 ft/year	Velocity ranges, in the area of concern from about 1 ft/year to over 600 ft/year (in high K zones, near water supply wells)
10	Constant porosity of 0.251	Constant porosity of 0.2	Constant porosity of 0.2

revealed the calibration results of its model, I recreated the conditions of the HRI model in a new homogeneous model. That model is listed in column 2 of Table 1 and represents the conditions, inputs, assumptions, and abstractions of the HRI model set, but has the added benefit of the ability to explicitly simulate contamination transport. This model is a surrogate for the HRI model, allowing an effective comparison. This comparison is in line with NRC guidance to

consider alternative conceptual models and compare them to the purportedly conservative base model. It also accurately reflects HRI's assumptions regarding the subsurface environment.

33. The third column of **Table 1** shows the new case I developed, which I label the ENDAUM heterogeneous case. It exemplifies the guidance in NUREG 1804 (at 2.2-89, concerning model uncertainty), which states:

“Evaluate ... alternative conceptual models.”

and

“Evaluate the treatment of conceptual model uncertainty in light of the available site characterization data. If adoption of a conservative model is used as an approach for addressing conceptual model uncertainty, *the reviewer should verify that the selected conceptual model ... is conservative relative to alternative conceptual models that are consistent with the available data and current scientific understanding.*” (emphasis added)

Simply put, HRI has represented its model as conservative and calibrated. The ENDAUM heterogeneous case has been created as an alternative conceptual (and numerical) model against which HRI's model can now be evaluated. As will be seen, not only is the ENDAUM heterogeneous case a perfectly valid alternative conceptual model, it is far more consistent with the available data (therefore, better calibrated) than the HRI model.

34. The new models cover exactly the same area encompassing the wells and units of concern, as shown in **Exhibit B, Figures 4 and 5**. The domain extends 15,000 feet east to west and 11,000 feet south to north. The model map is color coded according to the assigned K values at each model grid cell. Note that the homogeneous case, representing the HRI models, contains a single color. Note the channel features in the ENDAUM heterogeneous case (**Exhibit B, Figure 5**), where the lightest color represents the highest K zones (through which groundwater could flow the fastest) and the darkest color represents the lowest K values (which are generally barriers to groundwater flow).

35. I set up the models for two evaluations. The first evaluation was to recreate the water level history of the HRI 1991 Crownpoint pump test (HRI, 1992a, Attachment 82-1). In particular, I wanted to match the pre-pump test water levels and the immediate post-pump test water levels for ALL observation wells, because the better the calibration, the more plausible and reliable the model's predictions. Modeled predictions of uranium transport were the second evaluation set. In this set, both models simulated 10,000 days of mining operations (roughly 27 years) to determine if contamination of the nearby public water supply wells was plausible over that time period.

C. Modeling Results: Evaluation #1 (Calibration Study)

36. *Homogeneous (HRI representative) Case:* Exhibit B, Figure 11 shows the predicted drawdown cone of depression for the pump test, as predicted by the homogeneous (HRI representative) model. As expected, the drawdown outline is almost perfectly symmetrical. Exhibit B, Figures 12 and 13 show simulated water levels (called "potentiometric surface" contours, in feet above mean sea level) for a portion of the model area prior to the pump test and at the end of the test, respectively. The smooth contours are in line with the homogeneous nature of the model.

37. *ENDAUM Heterogeneous (Channel) Case:* Exhibit B, Figure 14 shows the predicted drawdown cone of depression at the end of the pump test as predicted by the Heterogeneous model. This figure compares qualitatively well with Exhibit B, Figure 10a, which shows the elongated drawdown trough directly produced by the pump test, consistent with the presence of sand channels. Exhibit B, Figures 15 and 16 show simulated water levels for a portion of the model area prior to the pump test and at the end of the test, respectively.

38. *Comparison of Results:* **Table 2** summarizes the results of this evaluation, including the target water level values from the monitor well data, the predicted water level values at those monitor locations for both models, and the errors associated with those predictions. The row labeled “root mean-squared error (RMSE)” integrates all of the errors into a single metric.<sup>5</sup> The smaller the combined error, the better the overall calibration. The results

**Table 2. Comparison of Calibration Results.**

Measured Heads		Predicted Heads: ENDAUM Heterogeneous Model (Channels)	Predicted Heads: Homogeneous Model (HRI)
<b>Pre-Pump Test</b>			
CP-2	6469	6470.36	6467.3
CP-3	6472	6471.31	6470.3
CP-6	6474	6470.9	6473.6
CP-7	6469	6466.11	6464.4
CP-8	6474.5	6473.13	6480
<b>Post-Pump Test</b>			
CP-2	6451.07	6449.8	6452.8
CP-3	6448.51	6448.2	6450.4
CP-6	6465.83	6464.95	6466.4
CP-7	6456.7	6458.9	6453.3
CP-8	6460.37	6457.9	6472.3
<b>Root mean-squared error</b>		<b>5.96</b>	<b>14.76</b>
Mass balance error		0.001	0.0009

show that the homogeneous case has a much greater error rate (2.5 times greater) than the heterogeneous case. Because the heterogeneous model shows a significantly improved qualitative and quantitative fit to the observed drawdown pattern, it is the most reliable model. The model conceivably could be improved further by more refinement and possibly by the addition of leakage from the overlying Dakota Sandstone aquifer.<sup>6</sup> Because the homogeneous

<sup>5</sup> The RMSE is literally the square root of the sum of the squares of each error point. The smaller the RMSE, the better the fit to the data, i.e., the better the calibration.

<sup>6</sup> I have raised the issue of leakage in earlier affidavits, and have pointed out evidence that it may exist in the area, either through a lack of hydraulic integrity of the confining unit or by faulting, or a combination thereof.

(HRI representative) model shows a poor qualitative fit to the observed drawdown pattern, and since its quantitative calibration match is three times (or more) as poor as that for the heterogeneous case, in my professional opinion, the HRI homogeneous model is not even plausible<sup>7</sup>. Moreover, had the NRC's groundwater review standards of NUREG-1804 been consistently applied to the HRI application, the HRI model would have been soundly rejected in favor of the calibrated ENDAUM Heterogeneous Case model that I prepared.

D. Modeling Results: Evaluation #2 (Contaminant Transport Study)

39. HRI used its uncalibrated and implausible model to predict the length of time for contamination to reach the nearest water supply well, NTUA-1, from the mining sites in Crownpoint and Unit 1. HRI's predicted travel times range from 178 years within the Crownpoint site to more than 2,500 years within the Unit 1 site (see, Exhibit B, Figure 1, which is a reprint of FEIS Figure 3.10.). I used the heterogeneous and homogeneous models described in **Table 1** to predict travel times for contamination from the Crownpoint site to reach NTUA-1. Since these models had been developed with the widely-used MODFLOW groundwater flow code (McDonald and Harbaugh, 1988), it was a simple matter to apply another widely used groundwater contamination transport code, MT3D (Zheng, 1990), to that flow output. Both of these programs are the de facto standards for their respective purposes. MT3D allows for many options in the simulation of contaminant transport. I chose the Total Variation Diminishing (TVD) option, which is a robust numerical technique to solve the underlying advection

---

<sup>7</sup> A plot of potentiometric surface from HRI's response to RAI #54 (HRI, 1996a, Attachment 54.1) suggests I may have been too generous to HRI. This plot appears to be from HRI's model for pre-pump test conditions. It suggests that HRI's match to the data is even worse than the match I obtained while trying to recreate the HRI model. Accordingly, HRI's calibration may be as much as 6 times worse than the calibration of the heterogeneous model.

dispersion equations. The transport simulations were set up to abide by all of the major numerical constraints that are considered accepted practice.

40. **Table 1** provides information on many of the important aspects of the transport simulations, including the configuration of the mining injection and production wells. As the table shows, a single 5-spot pattern was used to simulate the mining operation.<sup>8</sup> The pumping rate is 7,700 cubic feet per day, which equals the injection rate. These transport models were meant to be roughly representative of the mining. As **Table 1** states, the Crownpoint site mining is represented by a single 5-spot pattern covering roughly a sixth of the mine acreage, and net production flow equals a hundredth of the total planned rate. Given that, I could have added additional 5-spot patterns and increased the total flow rate. However, that would, if anything, likely lead to even more contaminant transport to NTUA-1 than is already shown by the ENDAUM heterogeneous model.

41. **Figure 17** in **Exhibit B** shows a close-up of the mining extraction area, along with the hydraulic conductivity (K) zones for the ENDAUM heterogeneous case. Note that the injector is in a high K zone, while most of the surrounding pumping wells are not. Because of that, in fact, the contaminant recovery capability of the pumping wells will not be efficient. Contaminants coming from the injection well area will easily move around and beyond the limited capture zones of the pumping wells, as shown in subsequent figures, and as suggested by the flow vector arrows in the **Figure 17**. This type of occurrence could easily be repeated again and again under cases where the aquifer is heterogeneous, such as the current condition. Those heterogeneous K zones themselves are approximations of what is likely there. It follows that if I

---

<sup>8</sup> Notably, the FEIS (Figure 2.1 at 2-3) includes a description of the intended five-spot pattern, but no scale information, or total numbers of injectors and producing wells. As HRI's Consolidated Operations Plan Revision 2.0 clearly shows (HRI, 1997, Figures 1.4-3, 1.4-5, and 1.4-8), there will be hundreds of injection and production wells at each mining site.

chose to refine the mining operation into many 5-spot patterns on a smaller scale, I would also be justified in refining the hydraulic conductivity zones into a smaller scale as well. In such a case, the same phenomena of contaminants escaping from the mining zone will occur.

42. My modeling of the Heterogeneous case stands in stark contrast to the homogeneous case shown in **Figures 18 through 21 in Exhibit B**. First, **Figure 18** shows the resulting velocity vector arrow patterns for the homogeneous case, which is representative of the HRI model. Note that the inferred capture of contaminants is nearly complete, judging by the flow patterns indicated by the arrows. Next, **Figures 19 through 21** show the results of the actual contaminant transport simulations for 5, 10 and 15 years of transport time, starting from the beginning of the mining activity at the 5-spot location. These images are part of a series of plume “snapshots” similar to those featured in the animation in **Exhibit C**. As these figures clearly show, the heterogeneous case, which is the more reliable case, since it is based on a calibrated model, leads to rapid transport of contaminants to the nearest two water supply wells, NTUA-1 and BIA-6. Moreover, the contamination reaches NTUA-1 in as little as seven years.

43. On the other hand, the HRI homogeneous model predicts that the contaminant plume will hardly move over the entire simulation period of about 27 years. This representation appears to be thoroughly consistent with the HRI model shown in **Exhibit B, Figure 1** and FEIS **Figure 3-10**. Since the HRI model sets are uncalibrated and implausible, the contaminant transport predictions they generate are also implausible. Yet they are in part the basis for the license granted by the NRC. The ENDAUM heterogeneous model, which shows a rapid travel pathway directly to the nearby water supply wells, is the sole calibrated model of the system to date. In that respect, it is currently the most reliable predictor of the consequences of mining at the Crownpoint site.

E. Aquifer Tests at the Crownpoint Site Were Designed Improperly and Could Not Have Detected Drawdown in the Overlying Dakota Aquifer

44. Vertical migration of mining fluids into overlying or underlying aquifers must be prevented because the fluids contain extremely high concentrations of toxic and radioactive substances. FEIS, Table 2.1 at 2-6. Vertical migration may occur through faults or fractures in the overlying or underlying "confining unit," as a result of erosional scouring of intervening beds, through artificial conduits like abandoned wells or unplugged boreholes, or because the mining zone is in direct contact with adjacent aquifers. Aquifer pump tests are the most commonly used assessment tool to determine if there is a hydraulic connection between the mine zone and overlying aquifer.

45. In the particular case of the Crownpoint mining site, demonstrating that mining fluids will be contained in the mining zones of the Westwater Canyon Member is critical. Any release of mining fluids into the overlying Dakota Sandstone could pose a pollution risk to three of Crownpoint's public water supply wells that are screened in both the Westwater and Dakota aquifers and located from 0.5 to 1.5 miles downgradient of the mine site. FEIS, Figure 3.9 at 3-23 and Table 3.11 at 3-24. Unfortunately, HRI's April 1991 pump test to determine if there is hydraulic communication between the Westwater and Dakota was designed and carried out in such a way that it minimized or eliminated opportunities for the detection of drawdown in Dakota observation wells. Nor can the results of that test be used as a basis for the NRC Staff's conclusion that "no aquifer interconnection was detected by the test (i.e., no draw down was detected by the Dakota Sandstone monitor wells)." FEIS at 3-29. In this section, I provide background information on how aquifer interconnections are determined and explain why I believe HRI's April 1991 pump test failed to prove that mining fluids will be contained in the mining area.

46. Interconnections between aquifers usually are discovered by pumping a well in one aquifer (the “pumping well”) and monitoring water levels in a wells or wells completed in the overlying or underlying aquifer (the “observation well”). The cone of depression can extend to upper or lower aquifers if a vertical interconnection exists. Depending on the degree of connection, the drawdown effect in the upper or lower aquifer can be subtle or pronounced. In either case, it is important that horizontal separation between the pumping well and observation well or wells be as small as possible, to maximize the possibility of observing an effect.

47. Based on my review of HRI’s reports on how the Crownpoint site pump tests were conducted and the results interpreted, I believe that their results do not support the conclusion that there is no hydraulic connection between the Westwater and the Dakota. Specifically, I reviewed the pump test reports themselves (HRI, 1992a), which HRI discussed in its responses to the NRC Staff’s RAI #81 and RAI #82 (HRI, 1996a). According to these reports, HRI built and abandoned monitor wells in the Dakota successively farther and farther away from the pumping well over a period of time. HRI’s rationales for abandoning these observation wells do not make hydrologic sense, as the examples that follow illustrate.

48. HRI constructed its first Dakota observation well, CP-4, about 500 feet east by southeast from its Westwater Canyon Aquifer pumping well, CP-5. This distance is at least an order of magnitude (10 times) greater than what is considered standard practice in conducting aquifer pump tests. Even the Mobil South Trend pump test for Unit 1 had two Dakota wells, both of which were less than 500 feet from the WCA pumping well. The closer the horizontal distance between the Dakota and WCA wells, the more reliable the result. The farther away, the more questionable the result.

49. Shortly after drilling CP-4, HRI abandoned it because of what it called a “lost drill pipe” (HRI, 1992a at 5). In its response to NRC RAI#82, HRI stated, “Problems [with CP-4] did develop *as anticipated*,” (*ibid.*, and HRI, 1996b, Attachment 82-1) but it did not explain why those problems were expected with such a typical well re-completion operation. Instead of constructing a new Dakota observation well closer to the WCA pumping well, HRI constructed one even farther east, twice as far away as CP-4. HRI then claimed that the new Dakota well, CP-1, which was now located approximately 1,000 feet away from the WCA pumping well, exhibited a “poor” barometric response. However, as HRI so clearly demonstrates in numerous figures accompanying its response to NRC RAI #84, changes in water levels caused by fluctuations in barometric pressure were insignificant (generally under 1 foot), compared with possible drawdown effects, which in the event of an aquifer interconnection could be as much as fifteen feet or more. HRI, 1996a (see, response to RAI #84, Figures 1 through 5). The final and only Dakota observation well that HRI ended up using in the test was well CP-10, located nearly 2,000 feet to the west of the WCA pumping well.

50. HRI offered no explanation for why an observation well located so far from the pumping well was used for this test. Several explanations are possible. One possibility is that the well was placed far enough away from the pumping well to ensure that no drawdown would be observed. Another is that differential scouring of the Brushy Basin created zones of interconnection near and to the east of the pumping well, but not to the west. In any event, the April 1991 pump test at the Crownpoint mining site could not accurately determine if the Dakota is or is not in hydraulic communication with the WCA in the region of the WCA pumping well.

51. Newly obtained information sheds light on this issue. That information is discussed in an addendum to this declaration.

## II. Unit 1 Site: ISL Mining Likely to Negatively Affect Underground Source of Drinking Water Outside of the Mining Area

### A. HRI's modeling of contaminant transport from Unit 1 to the Crownpoint municipal wells is non-conservative and flawed

52. I conducted a groundwater flow and transport modeling study for the Unit 1 site that is similar to the study I conducted for the Crownpoint site. In this Unit 1 model, I produced a conservative estimate of transport, which, once again, reflects a superior calibration to the local aquifer test data than HRI's model shows. Moreover, the model suggests that contaminants could reach the Crownpoint municipal water supply wells in less than 65 years from the commencement of mining at Unit 1. This is because the channelized nature of the WCA is as prevalent at Unit 1 as it is at Crownpoint.

53. As evidence that mining fluids will be contained in the Unit 1 mining zone and there is no vertical communication between the Westwater and the overlying Dakota, HRI presented a map of potentiometric surface contours generated by a pump test conducted by consultants for Mobil Oil Corp. in 1982. Thomas Prickett and Associates, 1983 (hereinafter, "Prickett Report"). That map is reproduced here as **Figure 9 in Exhibit B**. HRI argued that this plot, like a drawdown plot, indicated that the aquifer did not have a channelized fabric.<sup>9</sup> However, the figure shows that the contours are approximately 20 percent longer in the north-to-south direction than they are in the east-to-west direction. Interestingly, the direction of this skewness corresponds with the orientation of the ore body channels shown in the middle of the

---

<sup>9</sup> Included in this description was an unsupportable claim that it takes more than a few monitor wells to interpret a drawdown surface from a pump test. In fact, to determine an effect that runs counter to a claim of pure isotropy (HRI's claim), it only takes data from one pumping well and two monitor wells. It also referred to the Crownpoint test as a more "regional" aquifer test, when in fact both tests are on the same scale.

Unit 1 mining area in HRI's flow pathways diagram (HRI, 1996a, Figure 50-2; reproduced as **Figure 1 in Exhibit B**).

54. I have argued in previous written testimony and affidavits (Wallace, 1999a, 1999b, and 1999c) that the narrow, snake-like ore bodies depicted in several of HRI's reports<sup>10</sup> are highly correlated with the presence of buried sand channels. Moreover, I have provided specific evidence relating trough-like drawdown effects from HRI's own pumping tests that are likely caused by sand channelization in the same orientation as the ore body channels. I have done this for the Churchrock site, the Crownpoint site, and now for the Unit 1 site.

55. My Unit 1 model was constructed with this in mind. This model is based on the previous model developed specifically for the Crownpoint unit. The western boundary of the Crownpoint unit model was extended 15,000 feet to the west to include Unit 1. **Exhibit B, Figure 22** shows the new model layout, which still includes the Crownpoint municipal water supply wells. The hydrogeologic properties within the "added on" portion of the model were assigned based on the overall understanding of the hydrogeologic conditions within the site that are supported by the calibration results, literature data, and study of the site similar to Crownpoint (site analogues). The initial hydraulic conductivity zones that I assigned within the model are shown in **Exhibit B, Figure 23**. Two modeling tasks were considered in this study. The first task was to match the history of water levels induced by the Mobil pumping test, which utilized the pumping well 15M7 located within the Unit 1 area (Prickett Report at i). This interpretation is needed to calibrate the model within this area. The second task was to estimate the time of arrival of the possible contamination from Unit 1 to the closest water supply well, NTUA-1.

---

<sup>10</sup> See, e.g., Wallace, 1999a, Exhibits C (Figure 50-3) and D (Figure 8).

56. **Pumping Test from Well 15M7.** The data on the locations of the pumping well 15M7 and 27 observation wells were obtained from the Prickett Report (1983). Figure 24 in **Exhibit B** displays the location of the observation wells selected as targets (bold). These observation points were selected because they covered a representative area around the pumping well. The set of injection and pumping wells shown to the south of the pumping test area was selected to model the operations at the site as a part of the second task. Well 15M7 was pumped at the rate of 75 gpm for 24 hours. The average hydraulic conductivity estimated by Prickett and Associates (1983) based on this test is 0.55 ft/d. The Mobil consultants assumed the aquifer was homogeneous, so hydraulic conductivity was not allowed to vary from one location to the other.

57. **Pumping test simulation with homogeneous model.** As I did for the Crownpoint model, I replicated the calibration results for the Unit 1 (Mobil South Trend) pump test that HRI would have achieved with its homogeneous transport model. The hydraulic conductivity everywhere within the model was specified as 1.75 ft/d.<sup>11</sup> Although the Unit 1 pump test estimated the hydraulic conductivity as 0.55 ft/d, the HRI transport model previously discussed, which included Unit 1, had a hydraulic conductivity value of approximately 1.75 ft/d. Since this discussion ultimately concerns HRI's transport model, I used the value for their model and not from their test. The modeled potentiometric surface is shown in **Exhibit B, Figure 25**. That figure can be compared qualitatively to the actual test results shown in **Exhibit B, Figure 9**. The measured and modeled drawdowns are also compared in **Table 3a**. As can be seen from this table, the mean square root error is 40.9 feet.

58. **Pumping test simulation with heterogeneous model.** I conducted several modeling runs to calibrate the heterogeneous model. The calibration target was to minimize the difference between the measured and modeled drawdowns in the 7 target wells. The results of

this calibration are shown graphically in **Exhibit B, Figure 26** and summarized in **Table 3b** below. As the table demonstrates, the modeled drawdowns are in good agreement with the measured drawdowns and the mean square root error is 3.4 feet, as opposed to an error of 40.9 feet in the homogeneous case. In other words, the heterogeneous case shows a calibration *12 times more accurate* than the homogeneous case.

**B. HRI underestimated travel time of contaminants from Unit 1 to water supply well NTUA-1.**

59. In a similar manner to the transport modeling done for the Crownpoint model, the new calibrated hydraulic conductivity was incorporated into a transport simulation for Unit 1. A lixiviant injection rate of 7,700 ft<sup>3</sup>/d was modeled over a 10,000 day time period. The simultaneous pumping was modeled from four surrounding wells N1, N2, N3, and N4 (**Exhibit B, Figure 24**) with the pumping rate of 1,995 ft<sup>3</sup>/d. I used the same TVD transport methodology as I used for the Crownpoint transport model. The results of the transport simulation were examined to determine when the contaminant plume from the injection site reaches the well NTUA-1. As shown in **Exhibit B, Figure 27**, the simulated travel time for the first contamination to arrive at NTUA-1 is about 63 years from the beginning of the injection. Accordingly, the calculated travel time based on my calibrated heterogeneous model is *26 times faster* than HRI's calculated homogeneous case travel time shown in Fig. 3.10 of the FEIS. While 63 years can seem like a long time, it is about two or three generations of use of the Crownpoint wells, during which time the town and its surrounding Navajo communities will grow, using more groundwater as they do.

---

<sup>11</sup> I have also determined that the use of 0.55 ft/d also leads to a poor calibration, in any event.

**Table 3a. Results of Unit 1 Pumping Test Simulations Assuming Homogeneous Hydraulic Conductivity (HRI's Homogeneous Case)**

Well NN	Measured Drawdown, (ft)	Model Drawdown, (ft)	Root Mean Squared Error (ft)
15L64	42.26	10.7	
15M35	28.63	13.4	
15L73	14.46	8	
15L36	21.54	6.3	
16I81	19.01	7.5	
15M63	15.43	8.9	40.9

**Table 3b. Results of Unit 1 Pumping Test Simulations Assuming Heterogeneous Hydraulic Conductivity (ENDAUM's Heterogeneous Case)**

Well NN	Measured Drawdown, (ft)	Model Drawdown, (ft)	Root Mean Squared Error (ft)
15L64	42.26	45.1	
15M35	28.63	27.68	
15L73	14.46	13.9	
15L36	21.54	22.95	
16I81	19.01	19.1	
15M63	15.43	14.61	3.4

### III. Section 17: ISL Mining Likely to Affect Current and Future Uses of USDW

60. In essence, HRI's application for mining at Section 17 asserts that the ore zones in the Westwater Canyon Aquifer are hydraulically sealed from aquifers above and below. In addition, HRI's predictive groundwater modeling (of the Church Rock site in general) conveys the impression that excursions would take thousands of years to contaminate other sources of drinking water.

61. I have considered these assertions against the available evidence and through the use of standard, accepted hydrologic analysis approaches, and I have drawn opposite conclusions. The following sub-sections support my arguments that the ore zone in Section 17 is not sealed from other aquifers that are above and below it. Moreover, under conservative

assumptions, excursions could reach underground sources of drinking water in as little as 150 years, given anticipated water supply development two to three miles to the south of Section 17.

A. Available Evidence Indicates that the WCA is in Extensive Hydraulic Communication with the Overlying Dakota Sandstone.

62. Hilpert (1969) provides ample information and analysis on the lack of confinement between the WCA and the overlying and underlying aquifers.<sup>12</sup> He indicates that the Brushy Basin has a wide range of thickness in the area, “caused mostly by its intertonguing and grading at the base with the Westwater Canyon Aquifer but partly by its beveling southwestward under the pre-Dakota erosion surface.”<sup>13</sup>

63. Hilpert describes vertical fractures in the Church Rock Mine area, and in particular, a “strong steeply dipping fracture system that trended northeastward and along which the ore was mostly redistributed.” Hilpert at 77. Moreover, he describes a large “sombbrero” shaped ore body in the Dakota, also aligned with the same fractures. *Ibid.* The existence of the “sombbrero” shaped uranium ore lobe in the Dakota, directly over the Section 17 site, is perhaps the most dramatic affirmation of a vertical interconnection there. My interpretation of Hilpert’s description is that these fractures created hydraulic communication between the Dakota and the WCA. Dissolved uranium (perhaps oxidized by communication with the upper Dakota aquifer) redistributed along these fractures under former hydraulic gradient regimes. HRI’s model of ore genesis (a long lens-shaped zone caused by an abrupt change in uranium solubility between different levels of dissolved oxygen in the groundwater) could never support such a sombrero shape rising from a stem connecting two allegedly hydraulically isolated aquifers

---

<sup>12</sup> Hilpert also provides additional support for my findings regarding channels and their correspondence to actual ore zones. For example, in describing an ore body in the overlying Brushy Basin, Hilbert indicates that “the ore follows an ancient stream pattern” (Hilpert 1969 at 76).

B. Available Evidence Indicates that the Recapture Member Has No Confining Capabilities at Section 17.

64. The NRC Staff, citing HRI, claims that the Recapture Member “Shale” not only exists, but also is 150 feet thick under the Westwater at the Church Rock site. FEIS at 3-18. This assertion is contradicted by the majority of available evidence, including statements within the FEIS itself. For example, the FEIS states (at 3-8) that on a regional basis, the Recapture “is widely believed to interfinger with the underlying Cow Springs Sandstone [“CCS”], and several authors have combined the two units as one.” The FEIS (at 3-18) further states that old cross-sections through Section 17 indicate that the WCA is in direct contact with the underlying CSS, which is a regional aquifer. The FEIS, citing Peterson<sup>14</sup> (1980), also states that the Recapture does not occur in areas as little as one mile west of the Church Rock site, and that the WCA lies directly on top of the CSS aquifer there. *Ibid.* In addition, Figure 3 of the Cowan paper (1991)<sup>15</sup> indicates that the Recapture is thin to non-existent directly south of Section 17. It is interesting to note that the figure also shows the Brushy Basin is missing and/or thinning at the same approximate location. Finally, the shaft log for the United Nuclear Corporation Northeast Church Rock Mine located about two miles northeast of Section 17 shows that the Recapture is missing there as well. UNC, 2003.<sup>16</sup> These locations of documented, missing Recapture are summarized in **Exhibit B, Figure 28.**

---

<sup>13</sup> Moreover, Dr. Spencer Lucas, in his February 25, 2005, Declaration (¶¶ 24, 36-39), describes the Brushy Basin as being largely absent from Section 17.

<sup>14</sup> Peterson wrote at 131, “In the Church Rock area, the Westwater Canyon is underlain by the Cow Springs Sandstone . . . The Cow Springs intertongues with several Upper Jurassic units, including the Morrison and the Underlying Summerville Formation. The Cow Springs-Westwater Canyon contact is easily recognized in both drill cuttings and on electric logs because of the change to clean, well-sorted sandstone.” Figure 3 of Peterson’s paper, a general stratigraphic column in Section 13, shows the Westwater Canyon Member sitting directly on the Cow Springs Sandstone; no “Recapture” or shale member is depicted on the diagram.

<sup>15</sup> Dr. Lucas reviews the findings of the Cowan paper at length in his February 25 Declaration (¶¶ 40-51).

<sup>16</sup> The stratigraphic column for the UNCMine shaft is shown in Figure 10 of Exhibit D of Dr. Lucas’s Declaration.

65. A rigorous examination of documentation in HRI's application, elsewhere in the hearing record and in previous testimony by HRI's witnesses shows that there is little empirical support for HRI's and the Staff's finding that a confining layer of shale exists under the Westwater Canyon Aquifer at the Church Rock location.<sup>17</sup> Furthermore, the "stratigraphic column of the Church Rock site" that appears in Figure 3.7 of the FEIS (at 3-19) is likely a reproduction of a geophysical log for drill hole 2.8/17/7 that was included in addendums to the Revised Church Rock Environmental Report (HRI, 1993a) and is referenced on page 3-35 of the FEIS. I compared a copy of the log for 2.8/17/7 with the stratigraphic section in Figure 3.7 and they are quite similar. The NRC Staff relied heavily on the drill log for hole 2.8/17/7 to reach the conclusion that "[t]he Recapture Shale at the Church Rock site is about 55m (180 ft) thick. At the Church Rock site, drill hole 2.8/17/7 penetrated the total section of Recapture Shale." FEIS at 3-35. However, Dr. Lucas provides a convincing analysis that HRI and the NRC Staff misinterpreted this log, and that a confining shale layer — regardless of its name — does not lie below the Westwater. See Lucas Declaration, ¶¶ 27-35, attached as Exhibit X to Intervenors' Phase II Groundwater Presentation. Dr. Lucas concluded that the Westwater is in contact with the Cow Springs Sandstone at hole 2.8/17/7. Ibid., ¶ 32.

66. There are other reasons to doubt the existence of a confining layer underlying the WCA in Section 17. As I stated in ¶ 62 and ¶ 63 above, and in my January 1999 Testimony in Phase I of this proceeding (Wallace, 1999a), Hilpert's 1969 report for the U.S. Geological Survey stated that cross-sections of the Old Church Rock Mine in Section 17 indicate that the Westwater lies on top of a tongue of the Cow Springs Sandstone. As Dr. Lucas points out in his

---

<sup>17</sup> The FEIS does not distinguish explicitly between a Section 8 mine site and a Section 17 mine site, but refers to the "Churchrock" site because the site had not been bifurcated into two contiguous mining units when the FEIS was published in February 1997.

declaration (§ 35), a drill log for hole #53/41 located in Section 17 within 50 feet of Section 8 also shows a silty sand unit — not a “true” shale — underlying the lowermost unit of the Westwater.

67. Of equal concern is that a map of boreholes drilled in Sections 8 and 17 shows hole 2.8/17/7 located about 1,000 feet west of the Section 8 mine site and about 1,200 feet northwest of Section 17. See, Figure 2.6-5, Church Rock Revised Environmental Report (HRI, 1993a). A single borehole offset from the mining area cannot be considered representative of the area, since it does not penetrate the strata at the locations to be mined. As Dr. Lucas points out and as indicated throughout the Cowan report, the Recapture is a highly variable unit that does not have the geological characteristics of a true confining layer. If anything, its occurrence through the area of concern can only be considered as “spotty.”

68. Furthermore, HRI’s October 1993 revisions to the Revised Church Rock Environmental Report contains a listing of more than 620 boreholes in Sections 8 and 17, their total depths and whether they were logged. See, HRI, 1993b, Appendix G. This list is accompanied by a map (also labeled Appendix G) showing the locations of these holes. An examination of the list of boreholes and the map in the CRRER shows more than 70 holes with total depths of 1,000 feet or more. Many of those logs were used to prepare stratigraphic cross-sections that were included in both the original April 1988 Church Rock Environmental Report (HRI, 1988, Figures 2.6-6 through 2.6-8) and the revised CRER (HRI, 1993a, Figures 2.6-6 through 2.6-10). The logs for many of these wells would have shown the presence or absence of a shale unit underlying the Westwater, which bottoms out at approximately 950 feet below land surface at Section 17. But the vast majority of those logs were truncated just below the bottom of the Westwater, and others are not legible for detailed review. In my recent visit to HRI’s

Crownpoint office for review records there, I was unable to find any additional evidence that supported HRI's claim of significant, extensive, hydraulically confining Recapture shale.

69. In summary, HRI provided only two drill logs from scores of available candidate holes to support its assertion that the "Recapture Shale" is a continuous confining unit under the Westwater. The NRC Staff relied on only one of those logs for a hole (2.8/17/7) that is located more than 1,000 feet west of what will be the edge of the Section 17 mine area. Additionally, a confining layer is documented to be missing 2.5 miles northeast, about one-quarter mile west, and about 2.5 miles to the south of Section 17, and even at the Section 17 site itself, as shown in **Exhibit B, Figure 28**. Despite having abundant data on the subsurface geology in and around Section 17, HRI and the NRC Staff relied on information from just two well bores, and then misinterpreted the geophysical logs of those boreholes, to support their claims that the Recapture "Shale" is present under Section 17. Given the available data, I conclude that the Recapture is either fully missing from Section 17, or is so thin and discontinuous that it would not prevent hydraulic interconnections between the Westwater and the underlying CSS aquifer. Moreover, as Dr. Lucas points out in his declaration (§§ 12-14), the Recapture, where it does exist in the region, is not even a confining shale, but is largely a sandstone rock with silts mixed in.

C. Modeling indicates contaminants can be transported from Section 17 to a well or wells at the planned Springstead Housing Development two miles south of Section 17.

70. In this section I develop a conceptual model for a conservative consideration of groundwater flow between Section 17 and the proposed Springstead community. The model embodies another type of channelized flow, this time expressed through faulting impacts on blocks of sedimentary rock. The model is simply intended to develop a plausible scenario for how a community pumping water hydraulically upgradient, and several miles from Section 17

could still induce water flow from Section 17 to their wells. The model concludes with a calculation, using the industry standard Darcy's Law, that suggests that contaminants from the Section 17 mine could be pulled up-gradient toward anticipated water supply wells in the planned Springstead community.

71. The Springstead site is located in Section 30 of T16N, R16W between two and three miles southwest of Section 17 (Figure 29). White Rock Mesa to the west of Springstead is a raised block of sedimentary rock with the Westwater Canyon Formation exposed near the base (see Cowan, Figures 4,6, and 7). The mesas to the east of Springstead have similar profiles and elevations, as well as similar outcrop compositions. Quaternary-age alluvium fills the valleys between each mesa, including a surface drainage that bisects Section 30 from south to north.

72. Water supply wells at the Springstead development will likely be completed in the lower portion of the Westwater Canyon Aquifer or the upper portion of the Cow Springs Sandstone. I base this conclusion on (1) a review of Dr. Lucas's field study on the Jurassic rocks in the area of White Rock Mesa to the west of the site, (2) the surface geology, which is Dakota Sandstone on the north and Westwater on the south, and (3) a New Mexico State Engineer Office record that shows a 500-foot-deep well at the old Springstead Trading Post on the site. A copy of that well record is attached hereto as Exhibit D. Since the Westwater rests on the Cow Springs at some places in the area, it is reasonable to assume that mining fluids entering the lower part of the Westwater could also enter the upper part of the Cow Springs.

73. As my earlier affidavit (Wallace 1999b at 7) on the Church Rock site demonstrates, HRI's own pump tests show that a channelized condition exists in the WCA there, with the orientation being roughly north to south, which points approximately toward the

Springstead area. Moreover, faults oriented in the same general direction are also well known to exist in the area. The pipeline fault is but one example (FEIS, Figure 3.8 at 3-20).

74. Faults are simply planes along which rock units have shifted. Due in part to the juxtaposition of different types of rock against each other along their vertical planes of displacement, faults can create interconnections in some instances, and isolating barriers in others. The aquifer between Section 17 and the Springstead area can be conceptualized as a series of interconnected, slipped blocks of sedimentary rock and alluvium which are in some cases confined horizontally from other adjacent blocks through faulting. **Figure 29 in Exhibit B** considers a sandstone block sequence (dashed blue outline) in the WCA that connects the Section 17 mine site to the proposed Springstead site. In this conception, the faults are not treated as if they go through the Section 17 site. Rather, they bound it to the west and east. They are treated here as planes along which the blocks of rock may be displaced up or down.

75. The flow model considered here conceives of buried sedimentary blocks beneath the alluvium in the valleys. One set of blocks is postulated to form an effectively continuous “field” from Section 17 to an anticipated municipal well field at the north end of the proposed Springstead community, approximately 18,000 feet away. The well field is assumed to pump at a combined rate of 600,000 gallons per day (enough to supply a community of approximately 4,000 residents). The buried sedimentary blocks are considered to be a saturated aquifer that is 1,000 feet wide and 300 feet thick.

76. Darcy’s Law states:

$$Q = -K \cdot A \cdot (dh/dl)$$

Where:

- Q = pumping or volumetric flow rate (feet/day)
- K = hydraulic conductivity (feet/day)
- A = cross-sectional area for flow (feet squared)

dH = change in potentiometric surface (feet)  
dL = change in lateral distance (feet)  
(dH/dL) is termed the hydraulic gradient

Once the flow rate is calculated, the travel time can be determined.

$$V = Q/(A*n)$$

and

$$T = dL/V$$

Where:

T = travel time (days)  
n = porosity  
V = velocity (feet/day)

77. The pre-existing regional hydraulic gradient is considered to have a value of 0.007, directed from south to north (away from Springstead and toward Section 17). I assume a porosity of 0.2. Finally, I assume a hydraulic conductivity value of approximately 10 feet per day. This is well within the bounds for K used in my previous two models for the WCA. Accounting for the possibility that the channel continues south past Springstead, I cut the pumping rate in half for this calculation. I also factored in the opposing regional gradient. Utilizing these values in the equations in ¶ 76, wells pumping at the Springstead development could conceivably pull in contaminated water from Section 17 in 150 years, with under 200 feet of resulting water table drop at the pumping well site(s). Under this conceptual model, the drawdown magnitude is not an unreasonable value.<sup>18</sup>

78. Certainly the aquifer blocks I conceptualized would not be entirely isolated from adjacent and underlying or overlying aquifers. As I have stated, this is simply a conservative

---

<sup>18</sup> These conservative, first-order calculations of contaminant transport from Section 17 to the Springstead Housing Development are useful predictive tools for cases, like this one, in which little analysis of potential future adverse effects on a municipal water supply has been conducted. HRI's hydrologist, Craig Bartels, has criticized this approach in previous testimony (Bartels, 1999 at 26-49). Unfortunately, Mr. Bartels mischaracterized the context and assumptions of my 1999 channel flow calculations, and I responded in detail to these mischaracterizations in my April 1999 testimony (Wallace, 1999b at 3-9). In anticipation of a similar set of critiques from HRI on my Springstead analysis, I reiterate that my counter arguments would apply here again.

look at a possible outcome. As more and more data become available for a site, it becomes possible to transition to more realistic analyses and models. These presumably could show longer travel times. However, the channel flow exercise that I conducted for the Crownpoint site (Wallace, 1999a at 40-42) showed rapid transport from the mining region to the municipal wells at Crownpoint. Those predictions are not significantly different from the more realistic model predictions I presented for the Crownpoint and Unit I sites in this declaration. And as demonstrated herein, my Crownpoint and Unit I models are far more realistic and defensible than the uncalibrated model that HRI has used and that NRC Staff has accepted.

**IV. The Only Independent Critique of HRI's Hydrologic Model and the NRC Staff's Acceptance of it Has Never Been Refuted and Brings into Question the Wisdom of Leaving Important Hydrogeologic Issues to Resolution After Licensing**

79. The only independent review of the hydrogeological conceptual framework used by HRI was performed by a prominent and nationally respected hydrogeologist, Dr. Shlomo Neuman of the University of Arizona in Tucson, who was highly critical of the Crownpoint Uranium Project and the NRC's Final Environmental Impact Statement (1997). In my view, Dr. Neuman's criticisms of the hydrogeological conceptual framework of the CUP have never been successfully rebutted by either HRI or the NRC Staff. I discussed Dr. Neuman's views in my January 1999 testimony (Wallace, 1999a at 22-24 and Exhibit G), and I believe they are worth reiterating here because they are still consistent with repeated testimony of Intervenor's experts in this lengthy proceeding. Most important, his criticisms remain relevant in light of the fact that major hydrogeologic concerns about the Section 17, Unit 1 and Crownpoint mining sites will be left for resolution by hydrologic field studies after HRI's license has been adjudicated, and those studies will allow HRI substantial judgment and latitude in interpreting their results.

80. Dr. Neuman gave an invited presentation to NRC Staff on January 28, 1998,<sup>19</sup> in which he used the CUP and contents of the FEIS as a “case study” to “illustrate the complexity of hydrogeologic conceptualization, its numerous pitfalls and potential to constitute a major source of uncertainty in assessing the expected safety performance” of nuclear waste repositories and source material recovery facilities. Wallace, 1999a, Appendix G; attached hereto as **Exhibit E**. After describing the HRI project and showing various graphics from the FEIS, Dr. Neuman stressed that Westwater Canyon Aquifer “was considered to be hydraulically uniform, isotropic and perfectly confirmed” (emphasis in original slides). **Exhibit E** at 20. Dr. Neuman then concluded that the FEIS has failed to consider that drawdowns from pump tests “take weeks or months to develop and are hard to detect,” that pump tests often do not “establish hydraulic properties of confining units,” and that high injection pressures “may cause major leakage [between aquifers] without creating hydraulic fractures.” *Ibid.* at 22. He concluded that the “hydrogeologic Conceptual Framework behind the FEIS is flawed (neither realistic nor conservative) and therefore indefensible” (emphasis in original slide). *Ibid.*

81. In response to Dr. Neuman’s critique, the NRC Staff stated that while it agreed with his general points about the potential for misinterpreting pump test results, it disagreed with his overall conclusion that the “FEIS is seriously technically flawed and indefensible.” Holonich Memorandum, **Exhibit E**, at 3-5. HRI, in its February 19, 1999, response to the Intervenor’s Groundwater Presentation (hereinafter, “HRI Response Brief”), defended the Staff, saying, “Intervenors ignore the fact that the Staff determined that Dr. Neuman ‘did not have a complete understanding of all the information evaluated by the staff to determine the specific acceptability of HRI’s application. . . [and also] conveniently ignore the fact that when asked, Dr.

---

<sup>19</sup> The title of Dr. Neuman’s presentation was, “Hydrogeologic Conceptualization for Environmental Safety Assessment: Case Studies and Steps Toward a Strategy.”

Neuman 'stated that he did not dispute the staff's findings. . .' [nor] specifically identify anything in NUREG-1508 that he believed would disqualify the site from ISL mining." HRI Response Brief at 4-5.

82. To confirm that this was an accurate characterization of Dr. Neuman's response, I sent an e-mail message to him in February 1999 and received a reply on March 3, 1999. A copy of that reply is included in **Exhibit E** attached hereto. Dr. Neuman stated in part:

". . . I stand behind every statement that I made in my talk to the NRC staff on January 29, 1998 concerning the site. . . .On March 19, 1998, I participated in a teleconference concerning my above opinion about the hydrogeologic conceptual framework for the site with NRC staff. This teleconference has not changed my opinion about hydrogeologic conceptualization of the site in any way. . . .Any statement or statements made by the NRC concerning opinions that I allegedly voiced during this teleconference are those of the agency, not mine. I have never been given a chance to review and/or comment on such statements. . . .In particular, an NRC memo by Joseph J. Holonich, Chief of the Uranium Recovery Branch, addressed to Peter B. Bloch, Presiding Officer of the Atomic Safety and Licensing Board, dated April 20, 1998, misrepresents my association with the NRC and my opinions about the site."

83. I revisit Dr. Neuman's concerns because I believe they are confirmed by the evidence that I have presented in this declaration that demonstrates that HRI's groundwater characterization studies and modeling results suffer from a "flawed" and "indefensible" conceptual framework that the Westwater Canyon Aquifer is one giant sandbox through which groundwater will move at a snail's pace, never reaching drinking water supplies. I have shown that HRI performed its Crownpoint pump tests improperly (§§ 44-52) and that its contaminant transport model could not be calibrated closely with its own aquifer test data (§§ 36-38). And I have presented a conservative but realistic model showing how contaminants can reach Crownpoint municipal wells in seven years from the Crownpoint mining site and in 65 years from the Unit 1 mining site.

84. Furthermore, I am not persuaded that certain license conditions incorporated into SUA-1508 by the NRC Staff will resolve these concerns. Specifically, the license requires HRI to condition pump tests before injecting lixiviant to “determine if overlying aquitards are adequate confining layers” (L.C. 10.23) and to conduct an “aquifer step-rate injection (fracture) tests within the Church Rock site boundaries” (L.C. 10.31). As noted by Dr. Neuman seven years ago, and as I have shown in this declaration, pump tests can be conducted poorly and their results can be interpreted incorrectly, and-or with a non-conservative bias. These factors introduce judgment into the critically important task of determining interaquifer communication and finding fractures that could provide conduits for contaminant flow. Since HRI’s previous field work to characterize the aquifers at Crownpoint and Church Rock has suffered from serious limitations, I have no reason to believe that the tests prescribed in the license will be done any better or the results fairly interpreted *after the license has been fully adjudicated*.

85. For these reasons, it is my professional opinion that License Conditions 10.23 and 10.31 will not provide adequate assurance to the NRC or the public that mining fluids will not escape the mining zone and contaminate underground sources of drinking water at Section 17, Unit 1 and Crownpoint. Accordingly, the tests prescribed in those license conditions should be done *prior* to the completion of this adjudication, or the license should be revoked.

#### **V. Key Differences between Section 8 and the Sites at Section 17, Unit 1, and Crownpoint**

86. The Crownpoint, Unit 1 and Section 17 sites contain numerous and significant differences from the Section 8 sites. Among them are the following items:

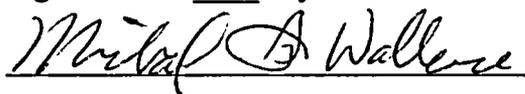
- a. The Westwater Canyon Aquifer (WCA) at the Unit 1 and Crownpoint sites is approximately twice as deep as WCA is at Sections 8 and 17.

- b. The Unit 1 and Crownpoint mining sites are in relatively close proximity to a set of major municipal water supply wells, which pump large quantities of groundwater from the same aquifer (the WCA) that HRI proposes to mine from.
- c. The direction of sand channelization is primarily in the west-to-east direction at these sites. The direction of sand channelization in the Section 8 site is primarily in the south- to-north direction, as seen in the ore zone map, Attachment E-2-2 to HRI's Section 8 RAP (HRI 2000).
- d. Section 17 contains underground mine workings that are not present at Section 8. These mine workings have filled with groundwater since mining and mine dewatering ceased in 1983. There are no water quality data for formation groundwater outside of these mine workings, and hence no means to obtain even a snapshot of baseline water quality at Section 17.
- e. Section 17 will be located within 3 miles of a major residential community of nearly 1,000 homes and 4,000 people, a development that will nearly double the current population of Church Rock Chapter when completed in 5 to 10 years and will likely be pumping groundwater at a rate 35 percent greater than the town of Crownpoint does now.

87. This concludes my testimony.

Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 1<sup>st</sup> day of March 2005.



Michael G. Wallace, MS

# EXHIBIT A

**Michael Wallace**  
**Curriculum Vitae**

**Education:**

M.S. in Hydrology, University of Arizona, Tucson, AZ, USA (1989)

B.S. in Plant and Soil Science (Environmental Studies specialization), Southern Illinois University, Carbondale, IL, USA (1980)

**Work History:**

2004 – present, Principal, MW&A. Earth Sciences consulting

1997 - 2004, Earth Sciences Consultant to Sandia National Laboratories (through various sub-contractors)

1990-1997, Senior Hydrogeologist, RE/SPEC Inc., Albuquerque, NM

1986 -1990, Staff Hydrogeologist, IT Corp., Albuquerque, NM

1982-1986, Hydrologic Technician, Research Assistant, University of Arizona, Tucson AZ

**Technical Experience Summary:**

Specific experience with a wide array of techniques in the quantitative and statistical analysis of ground water and other earth science problems. These techniques include 3-D modeling of flow and solute transport, vadose zone modeling, multi-porosity flow and transport modeling, stochastic processes, probability modeling, ground water resource optimization, NAPL transport in the subsurface, hydraulic test analyses, coupling of rock mechanics with ground water flow codes, coupling of geochemical analyses with ground water flow and solute transport analyses, and finite element numerical model development.

Contributor on several investigations on viability of Yucca Mountain hydrogeology for long term disposal of high level radioactive waste. Also primary reviewer of a 3D regional hydrogeologic numerical model of the Yucca Mountain area conducted by scientists at Los Alamos National Laboratories. Most recently, pioneered the use of a video game engine to produce a scientific analysis. This study concerned potential volcanic dike intersections with the planned repository. The novel analysis, which provided significant benefits to the client, was conducted on an extremely tight schedule and was completed under budget.

Principal analyst in a groundwater flow and transport modeling effort for the Waste Isolation Pilot Project's (WIPP) Performance Assessment (PA) program. Responsibilities include interaction with a large multidisciplinary body of earth scientists, physicists, and mathematicians; assimilation of information and diverse concepts; and the design, implementation, and interpretation of a model acceptable to the client, regulators, various scientific oversight panels, and other stakeholders. Currently supporting the qualification of an advanced code (nSIGHTS) which merges uncertainty analyses with aquifer pump test analyses and interpretation.

Developed a 3D deforming mesh program in C++. Led the development of specialized application interfaces for Visualization Toolkit (VTK) and ParaView, codes which are

compatible with parallel processing scientific applications that support the Advanced Supercomputing Initiative (ASCI). Led a qualification effort for the structural mechanics code JAS3D, a 3D finite element program design to solve large quasi-static nonlinear mechanics problems. Performed qualification work in support of thermal transport analyses associated with the Yucca Mountain Project.

Principal investigator on seven (WIPP) scenario screening efforts. Although all of the efforts were completed on schedule and within budget, one effort was successfully completed at less than a tenth of the cost originally estimated by the project. That effort also led to the first water table contour map for the WIPP vicinity.

Co-investigator in a 3-D paleohydrological / climate change consequence modeling study of the upper groundwater system in the WIPP region.

Extensive experience working as part of interdisciplinary teams to evaluate the hydrologic performance of waste containment systems. On WIPP, helped develop a numerical simulator that analyzed the coupled processes of salt creep and brine inflow, related to excavations into the Salado Formation. On the Stripa project (Sweden) and the Finnish nuclear repository program, helped develop numerical simulators that analyzed the coupled processes of cement seal degradation and ground water inflow.

Experience with a large number of additional ground water modeling projects. These projects include a two dimensional study of ground water flow and contaminant transport through the Capitan Reef aquifer of Southeastern New Mexico, several 3D flow and solute transport modeling projects associated with injection of hazardous wastes into saline aquifers, and several modeling studies associated with the design of ground water remediation systems throughout the U.S.

Conducted a series of unsaturated flow and transport modeling studies of the Yucca Mountain site using three different mathematical techniques. The results of these analyses were used to assess the likelihood of landfill contaminants reaching the water table. Conducted an unsaturated zone modeling study that was a factor in the State of New Mexico's strengthening of the state's environmental requirements for oil and gas operations in the San Juan Basin.

Extensive expert witness and litigation support experience (see related section).

### **Litigation Support Experience:**

Expert witness support on behalf of a coalition of organizations regarding an application by a mining company to develop three in-situ uranium leachate mines in the vicinity of Crownpoint, NM, USA., 1997, 1998, 1999, 2002, 2003. Client Attorneys; New Mexico Environmental Law Center, Santa Fe, NM. Client contact info: Eric Jantz, phone; 505-989-9022, Also Chris Shuey; 505-262-1862

Expert consultant to U.S. Army Corps of Engineers (Department of Defense), as a review panel member concerning a long-term regional groundwater flow model developed for the City of Gallup, New Mexico. This is popularly known as the G-22 Experts Panel. Hearing No. 99-003-OSE File No. G-22 and more.

Litigation support with regard to a water rights dispute in a karst aquifer, Eddy County, NM. 1999, 2002

Scientific studies and expert witness support with regard to a proposal to dispose of oil field brines in a deep brine aquifer in the Delaware Basin in southeastern New Mexico. State of New Mexico, Before the Oil Conservation Division, Case No. 10693. 1993, Santa Fe, Representing Pronghorn Disposal Systems, Inc. Client attorney: Karen Aubrey, Santa Fe, NM

Litigation and expert witness support with regard to the "Vulnerable Area" of the San Juan Basin in northwestern New Mexico. State of New Mexico, Before the Oil Conservation Commission, Case No. 10436. 1992, Santa Fe. Representing Southwest Research and Information Center. Client attorney: Doug Meiklejohn, President, New Mexico Environmental Law Center, Santa Fe, NM , phone; 505-989-9022

Expert witness support with regard to a landfill permit hearing. State of New Mexico, Before the Secretary of the Environment Department, No. SW 91-01, 1991, Alamogordo, NM. Transcripts of proceedings, solid waste permit hearings. Representing the U.S. Air Force. Client attorney: Lt. Col. John Spurlin, U.S.A.F., phone; 623-536-7283

Litigation support with regard to a leaking ditch maintained by the Middle Rio Grande Conservancy District (MRGCD), 1991, Client Attorney: Ron Childress, Albuquerque, NM

Expert witness support with regard to a water rights dispute, Sierra County, NM., 1991, Client Attorney; Fred Abramowitz, Albuquerque, NM

Numerous presentations, meeting participation, and other interaction with the USEPA and the National Academy of Sciences (NAS) with regard to permitting activities associated with the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The WIPP is the nation's premier permanent repository for the disposal of radioactive waste.

### Selected Publications and Abstracts:

Arnold, B.W.; Zyvoloski, G.; Economy, K.; and Wallace, M. 2003. "Thermal Transport in the Saturated Zone Site-Scale Model at Yucca Mountain." *Proceedings of the 10th International High-Level Radioactive Waste Management Conference (IHLRWM), March 30-April 2, 2003, Las Vegas, Nevada*. Pages 301-306. La Grange Park, Illinois: American Nuclear Society.

J.L. Ramsey, R. Blaine, J.W. Garner, J.C. Helton, J.D. Johnson, L.N. Smith, and M. Wallace, 1998, *Radionuclide and Colloid Transport in the Culebra Dolomite and Associated Complementary Cumulative Distribution Functions in the 1996 Performance Assessment for the Waste Isolation Pilot Reliability Engineering and System Safety 69* (2000). Elsevier Press.

Wallace, M., J. Ramsey, A. Treadway, M. Tierney, and D. Coffey, 1998, *Aquifer Model Complexity at the Waste Isolation Pilot Plant (WIPP)*, 1998 Spring Meeting of the American Geophysical Union, Boston, MA.

Marani, M., G. Grossi, F. Napolitano, M. Wallace, and D. Entekhabi, 1997, *Forcing, Intermittancy, and Land Surface Hydrological Partitioning*, *Water Resources Research*, Vol. 33, NO. 1, pages 167-175, Jan, 97.

Wallace, M.G., 1994, *Three-Dimensional Groundwater Refraction Patterns in the Northern Portion of the Delaware Basin. A Modeling Study*. American Geophysical Union 1994 Fall Meeting, San Francisco, CA.

Wallace, M. G., 1993, *A Total Dissolved Solids Map for the Northern Portion of the Capitan Aquifer*, New Mexico Geological Society 44th annual field conference and Guidebook, sponsored by the New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM.

Corbet, T., and M. G. Wallace, 1993, *Post Pleistocene Patterns of Shallow Groundwater Flow in the Delaware Basin, Southeastern New Mexico and West Texas*, New Mexico Geological Society 44th annual field conference and Guidebook, sponsored by the New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM.

Wallace, Michael G., and Tracy L. Christian-Frear, 1992, *New Tools to Aid in Scientific Computing and Visualization*, 3rd International High Level Radioactive Waste Management Conference, April 12-16, 1992, Las Vegas, Nevada

Alcorn, S. R., W. E. Coons, T. L. Christian-Frear, and M. G. Wallace, 1991, *Theoretical Investigations of Grout Seal Longevity. I. Geochemical Modeling of Grout-Groundwater Interactions - Flow and Diffusion Models*, Stripa Project Technical Report -24, Stockholm, Sweden

Alcorn, S. R., T. L. Christian-Frear, and M. G. Wallace, 1991, *Degradation Modelling for the Concrete Silo in TVO's VLJ Repository*, Report YJT-91-09, Nuclear Waste Commission of Finnish Power Companies

Wallace, M., J. M. Pietz, B. Lauctes, J. B. Case, and D. E. Deal, 1990. *Coupled Fluid-Flow Modeling of Brines Flowing Through Deforming Salt Around the Excavations for the Waste Isolation Pilot Plant (WIPP) in the Permian Salado Formation*, Proceedings, Waste Management '90, Tucson, AZ.

Wallace, M., 1989. *A Three Dimensional Analysis of Flow and Solute Transport Resulting from Deep Well Injection into Faulted Stratigraphic Units*, M.S. Thesis, University of Arizona, Tucson, AZ.

Wallace, Michael G., and John Pietz, 1989. *A Three Dimensional Flow and Solute Transport Model of a Deep Well Injection System*, Proceedings: "Solving Groundwater Problems with Models", Feb. 7-9, 1989, Indianapolis, Indiana, jointly sponsored by the NWWA and the IGWMC.

Niou, S., J. Case, J. Pietz, M. Wallace and J. Zurkoff, 1987. *Coupled Fluid Flow and Salt Creep Analysis for Room Saturation of a Salt Repository*, Proceedings, International Waste Management 87, Tucson, AZ.

#### **Selected Consultant Reports:**

Wallace, M., 2004, *Number of Waste Packages Hit by Igneous Intrusion*. ANL-MGR-GS-000003. Prepared through Sandia National Laboratories for the Yucca Mountain Project

Wallace, M., 1996, *Potential Long-Term Effects of Potash Mining on Hydrogeologic Conditions in the Culebra Aquifer. Technical Report for Features, Events and Processes (FEP) package NS-11*. prepared for Sandia National Laboratories, WIPP Project.

Wallace, M., 1996, *Impacts of Interconnections with other Units on Hydrogeologic Conditions in the Culebra Aquifer. Technical Report for Features, Events and Processes (FEP) packages NS2, NS3, and NS7b*. prepared for Sandia National Laboratories, WIPP Project.

Wallace, M., and others, 1995, *Flow and Transport in the Dewey Lake/Dewey Lake Conceptual Model. Technical Report for Features, Events and Processes (FEP) package NS1*. prepared for Sandia National Laboratories, WIPP Project.

Wallace, M., 1995, *Potential Impacts of Climate Change on Groundwater Flow and Transport Conditions in the Culebra Aquifer. Technical Report for Features, Events and Processes (FEP) package NS-8b*. prepared for Sandia National Laboratories, WIPP Project.

Corbet, T. and M. Wallace, 1993, *Input from the Regional Flow Model to the WIPP Performance Assessment*. Monitored Milestone NS60M. prepared for the U.S. Department of Energy.

*Comparative Analysis of the Multiphase Flow Models, PORFLOW, TOUGH, and TRACRN*, 1993, Draft technical report prepared by RE/SPEC Inc. for Benchmark Environmental Corporation, Albuquerque, NM.

*Holloman Air Force Base Landfill Application / Permit Plan Report (draft)*, 1992, Technical report prepared by Tierra Engineering Consultants, Inc., and RE/SPEC Inc. for the U.S. Army Corps of Engineers.

*Degradation Modeling for the Concrete Silo in TVO's VLJ Repository*, 1990. Technical report prepared by RE/SPEC Inc. for Teollisuuden Voima Oy, Helsinki Finland.

*Engineered Alternatives Task Force, Culebra Far-Field Model*, 1990 report, prepared by International Technology Corporation, Albuquerque, New Mexico, for Westinghouse Corporation, Carlsbad, NM.

*Ground Water Monitoring Waiver U3ax/bl Land Disposal Unit*, Nevada Test Site, Mercury, Nevada., 1989, Prepared by IT Corp. on behalf of REECo Inc. for the U.S. DOE, Nevada Operations Office.

*Brine Sampling and Evaluation Program*, 1988 report, prepared by International Technology Corporation, Albuquerque, New Mexico, for Westinghouse Corporation, Carlsbad, NM.

*Application for Exemption to Continue Underground Injection of Banned Hazardous Waste*, prepared by International Technology Corporation, Austin, Texas, for confidential client, Texas, 1988.

*Application for Exemption to Continue Underground Injection of Restricted Hazardous Waste*, prepared by International Technology Corporation, Austin, Texas, for confidential client, Texas, 1988.

*Application for Exemption to Continue Underground Injection of Restricted Hazardous Waste*, prepared by International Technology Corporation, Austin, Texas, for confidential client, Ohio, 1988.

*Action Line Plan, \_\_\_\_\_ Landfill Site, \_\_\_\_\_ County, CO.*, September 1988. prepared by International Technology Corporation, Denver, Colorado, for confidential client, Colorado.

*Plume Remediation Plan, \_\_\_\_\_ Landfill Site, \_\_\_\_\_ County, CO.*, November 1988. prepared by International Technology Corporation, Denver, Colorado, for confidential client, Colorado.

*Program and Schedule for Ground-water Cleanup, \_\_\_\_\_ Toluene Site*, 1987 report, prepared by International Technology Corporation, Denver, Colorado, for confidential client, Colorado.

# EXHIBIT B

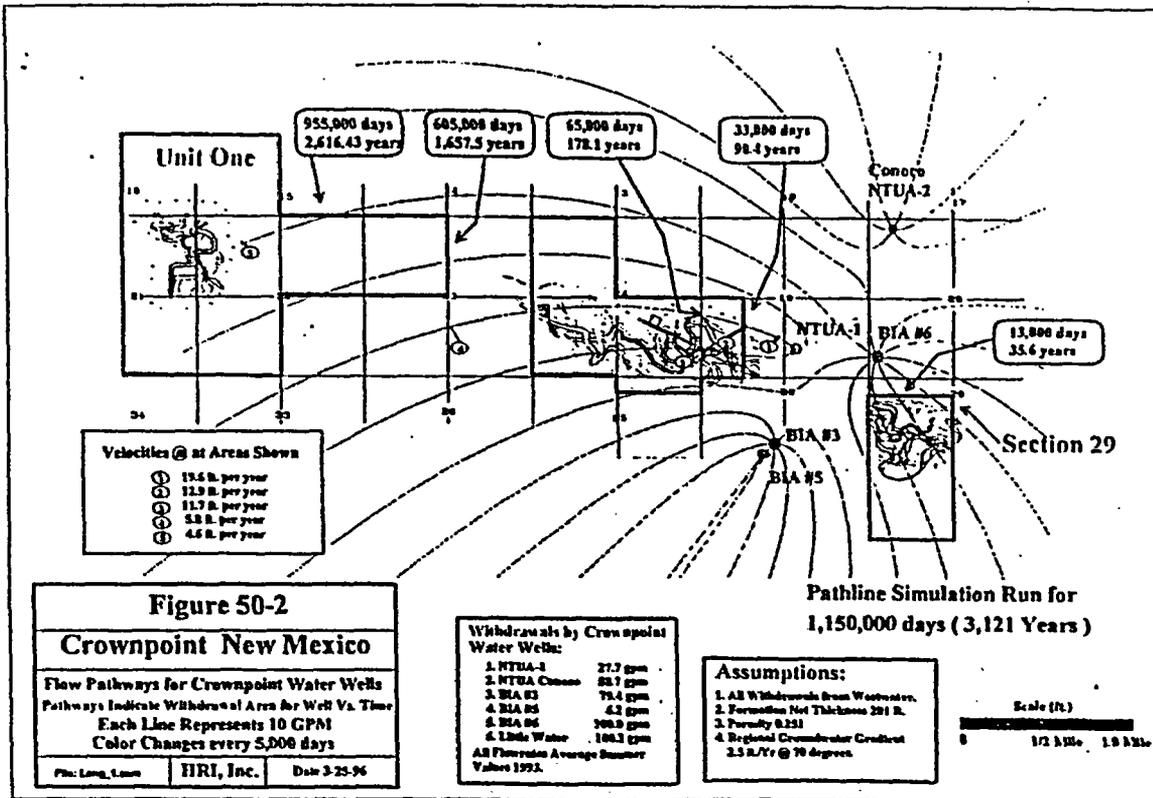
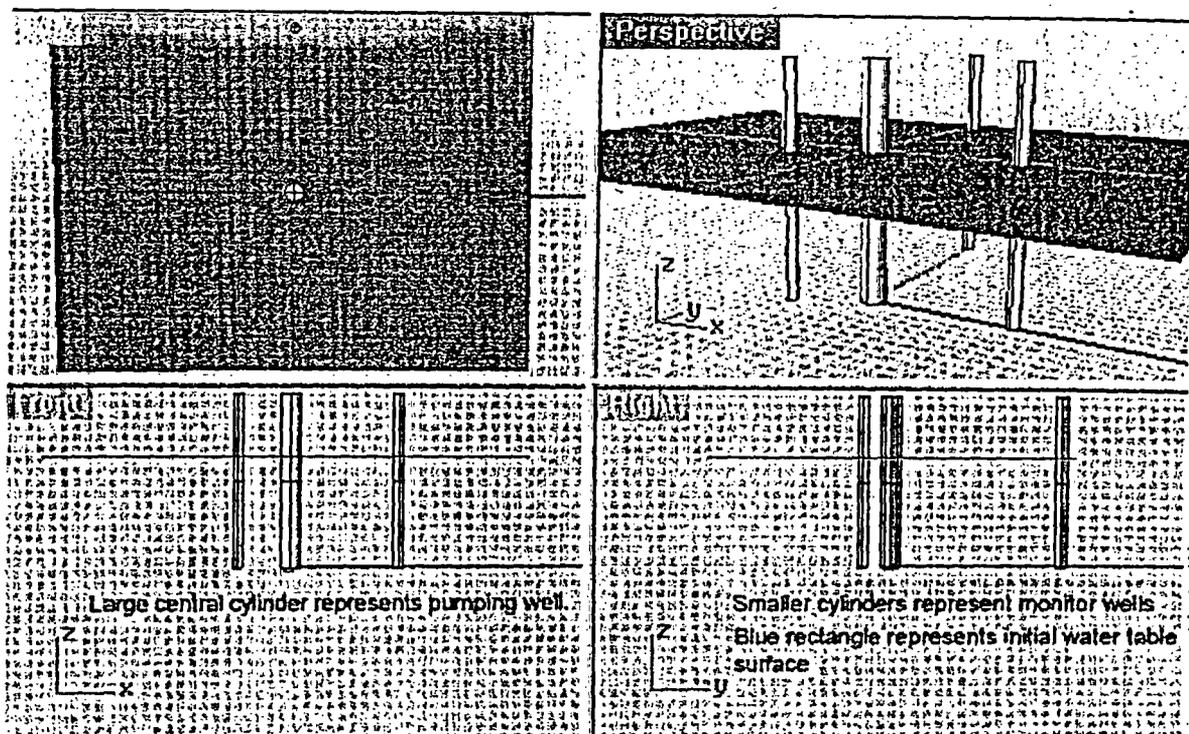
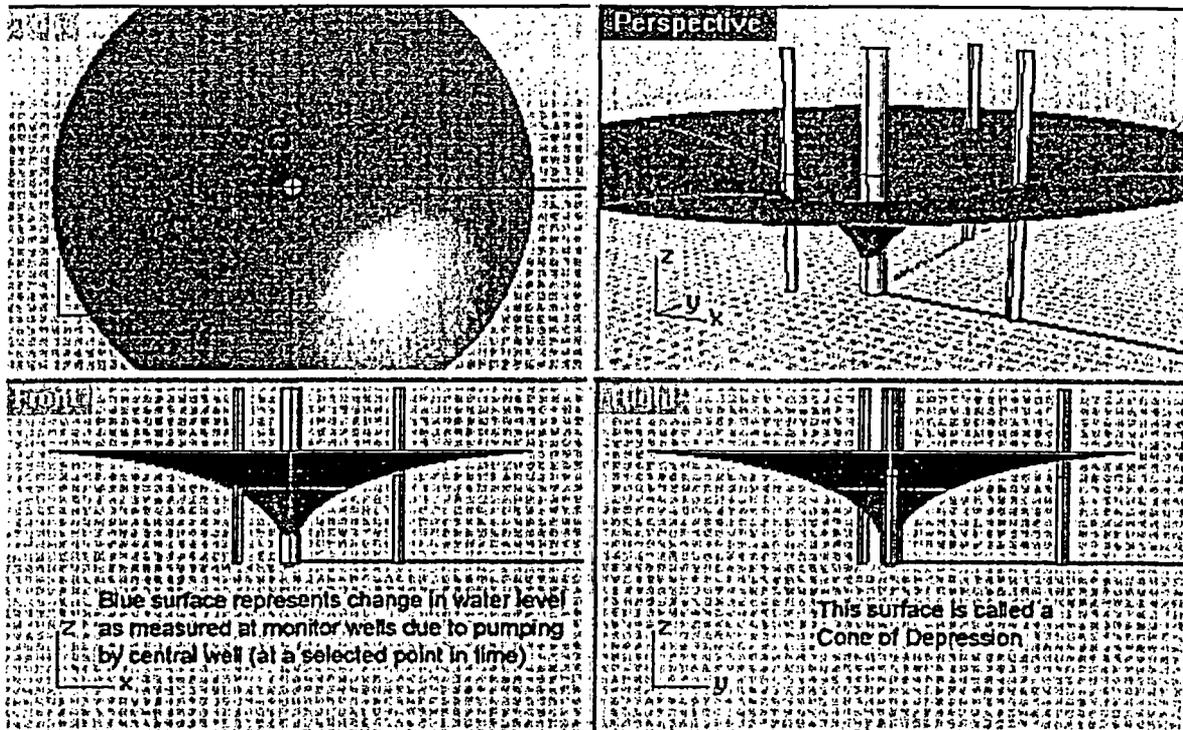


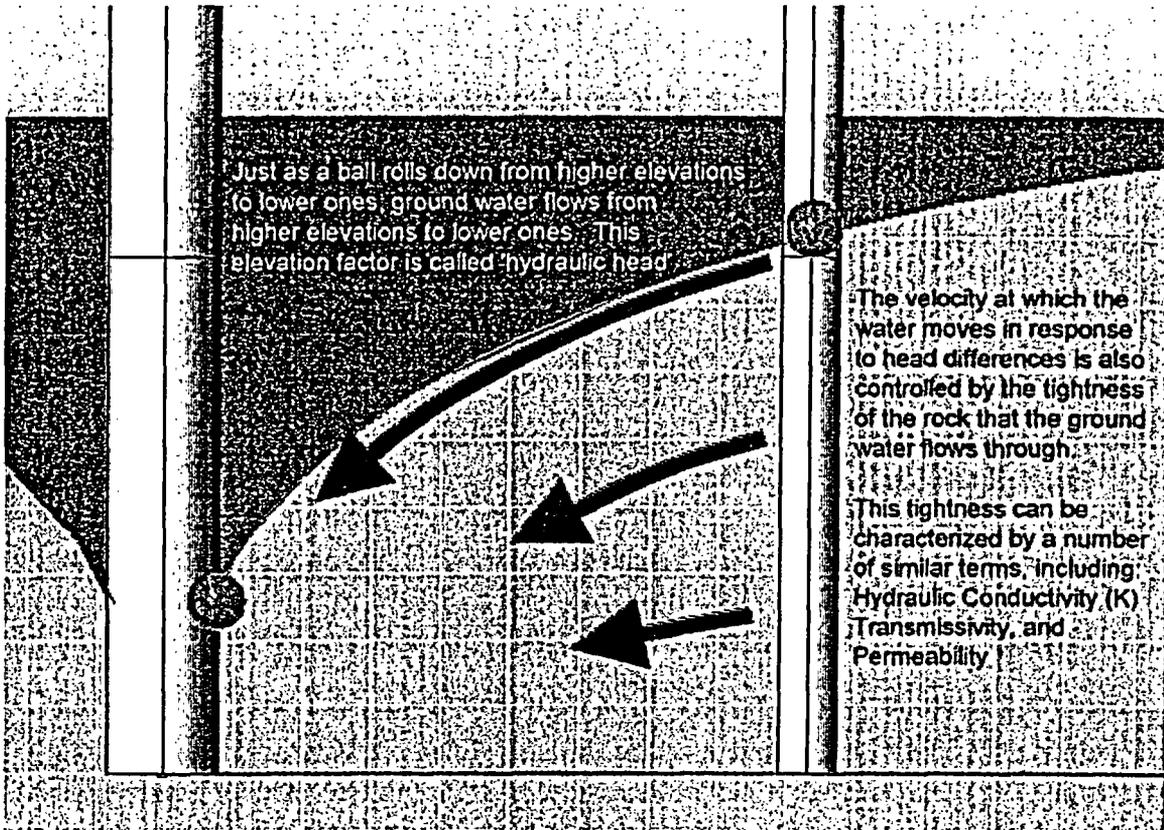
Figure 1. HRI's Ground Water Flow and Transport Model. Reprint of a model result figure.



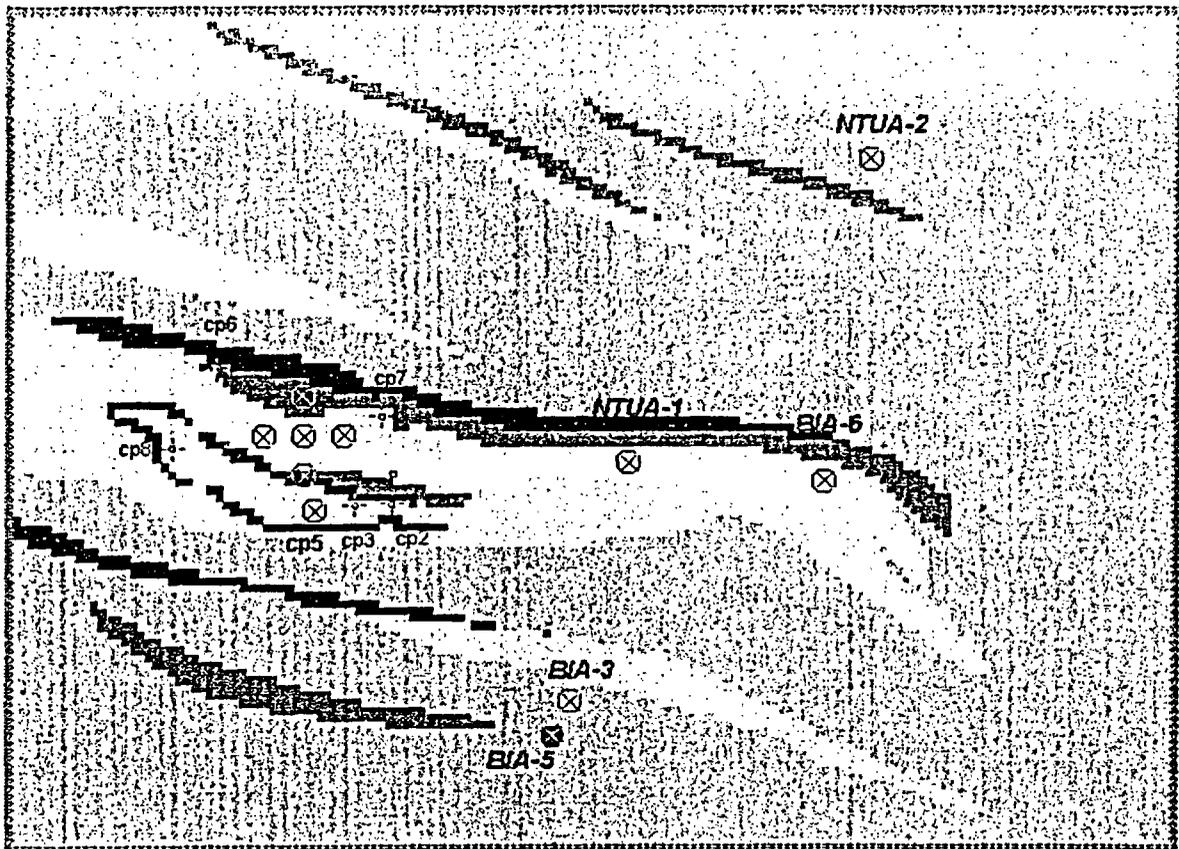
**Figure 2. Aquifer Pump Test Basics. Four views of a pump test layout consisting of one pumping well surrounded by three monitor wells.**



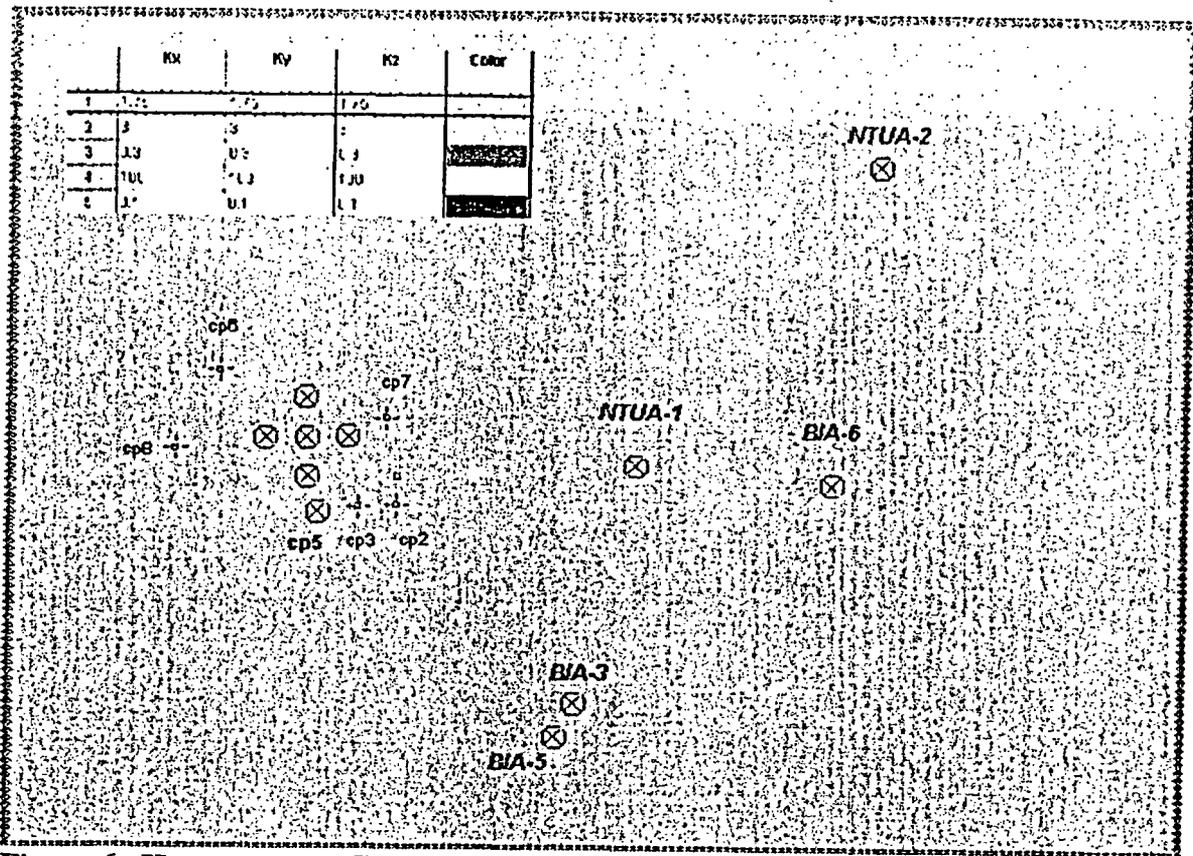
**Figure 3. Cone of Depression Caused by an Aquifer Pump Test. Four views of an idealization of this phenomena.**



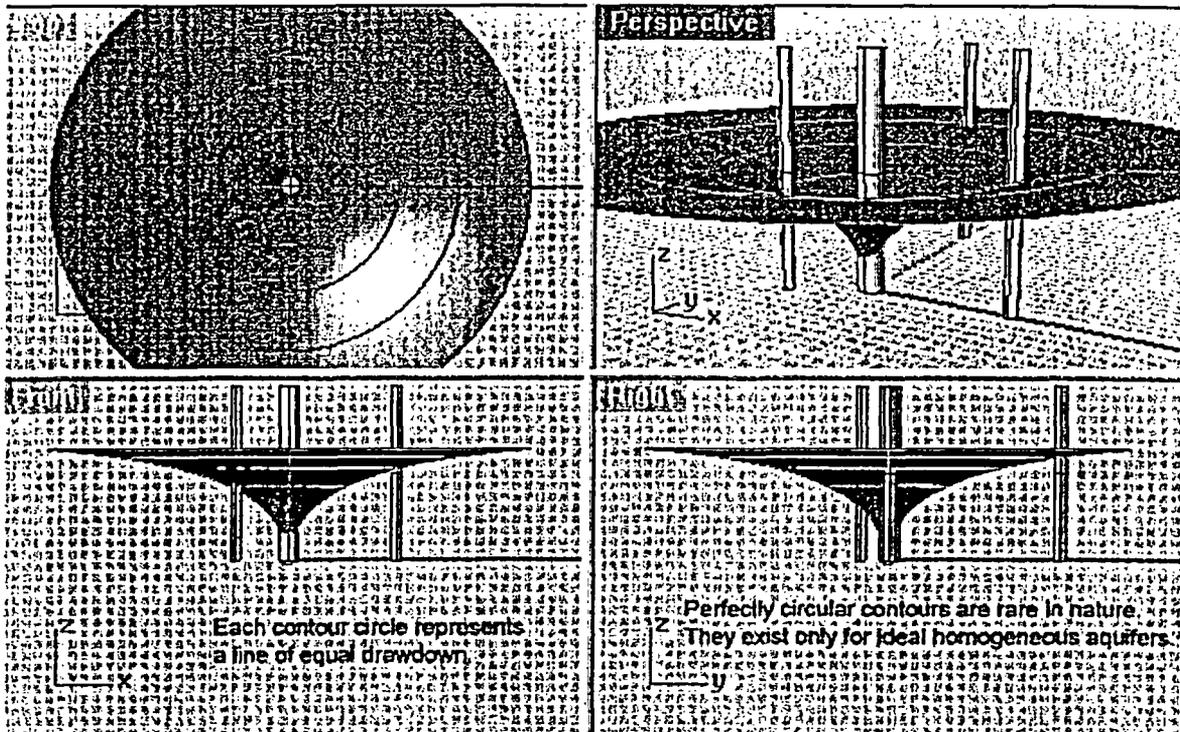
**Figure 4. Ground Water Flow as Controlled by Hydraulic Head Differences and Hydraulic Conductivity, Permeability, or Transmissivity.**



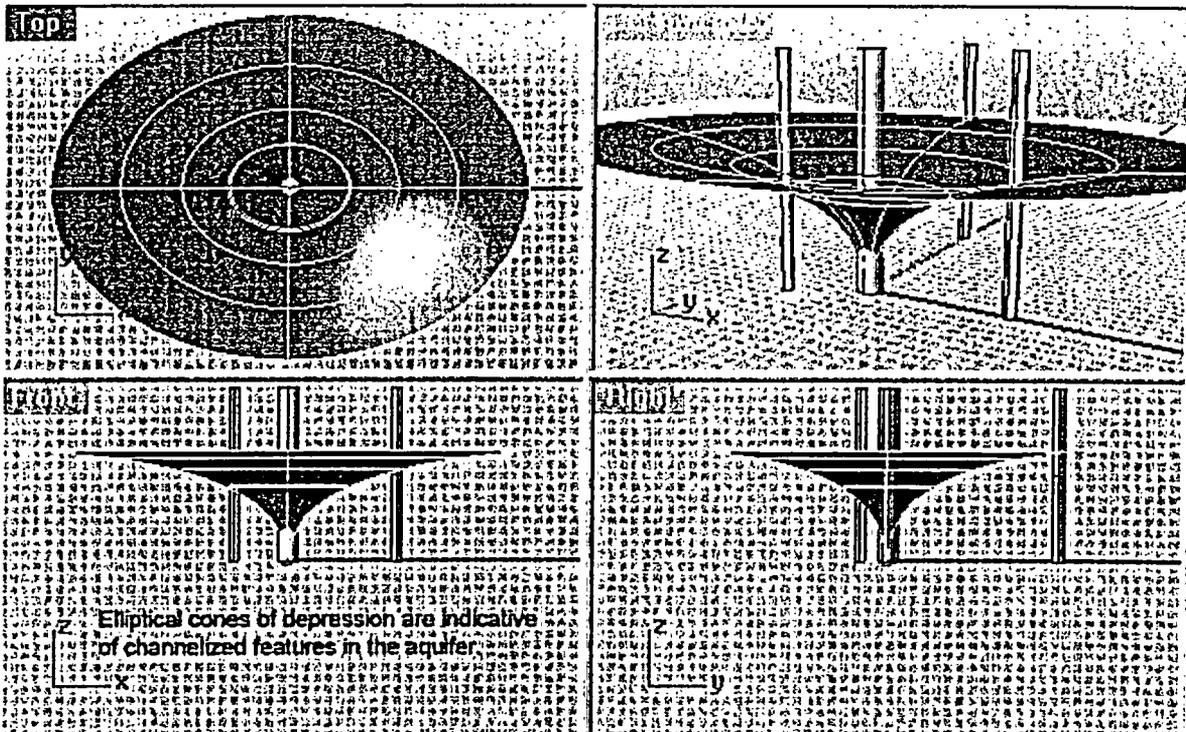
**Figure 5. Heterogeneous Ground Water Model. Model shows channelized zones of different degrees of hydraulic conductivity (K). Model also depicts a portion of the proposed mining area (around and about the 'cp' pump test wells) and the nearby Crownpoint water supply wells which are completed in the same aquifer.**



**Figure 6. Homogeneous Ground Water Model. Model shows only one zone of a single value of hydraulic conductivity (K). Model also depicts a portion of the proposed mining area (around and about the 'cp' pump test wells) and the nearby Crownpoint water supply wells which are completed in the same aquifer.**



**Figure 7. Contour Plotting of a Cone of Depression. This principle can be applied to contouring of water tables and hydraulic heads as well.**



**Figure 8. Contours Associated with a Non-Radially-Symmetric Cone of Depression. Elliptical, or irregular cones of depression are clear indicators of aquifer heterogeneity.**



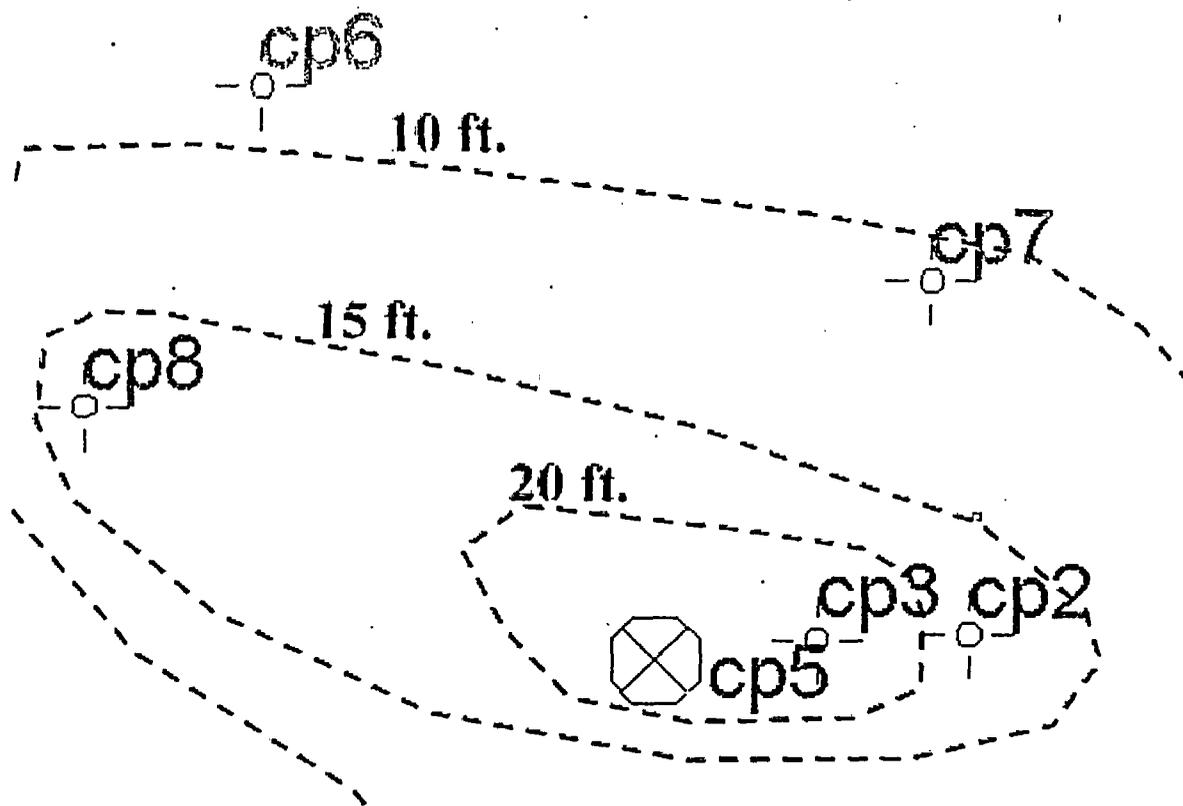
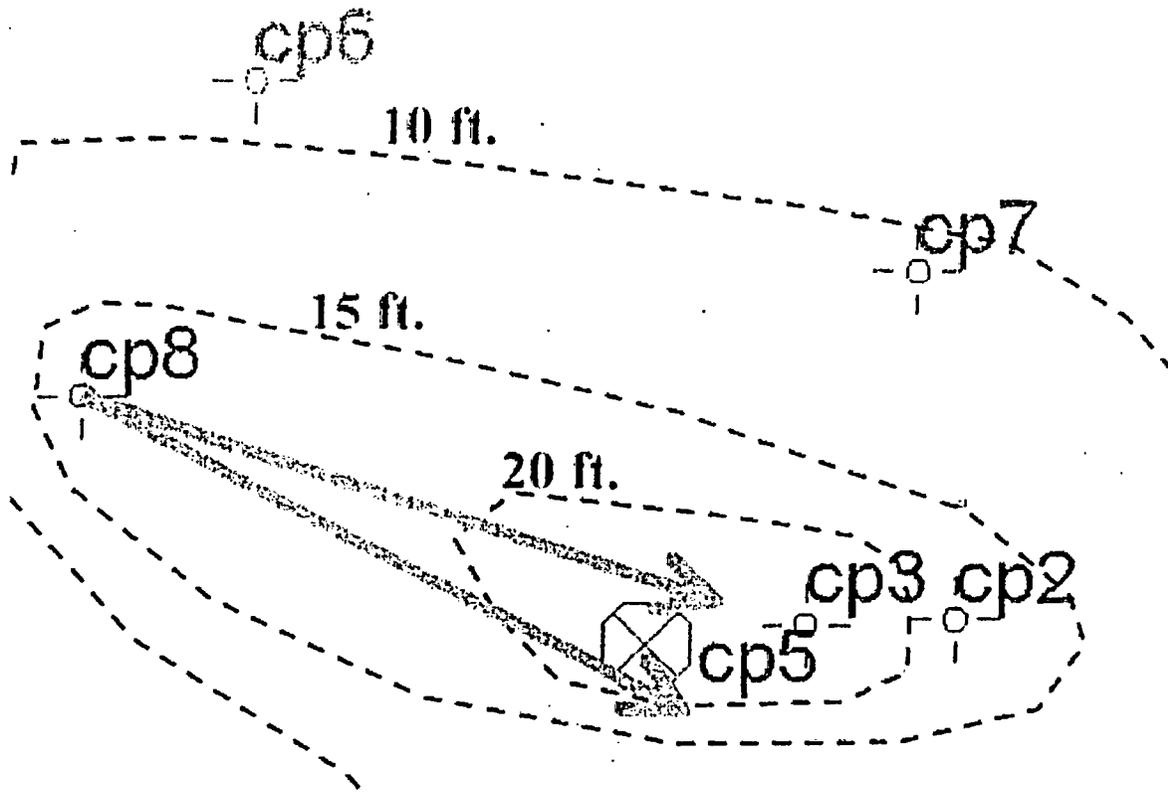
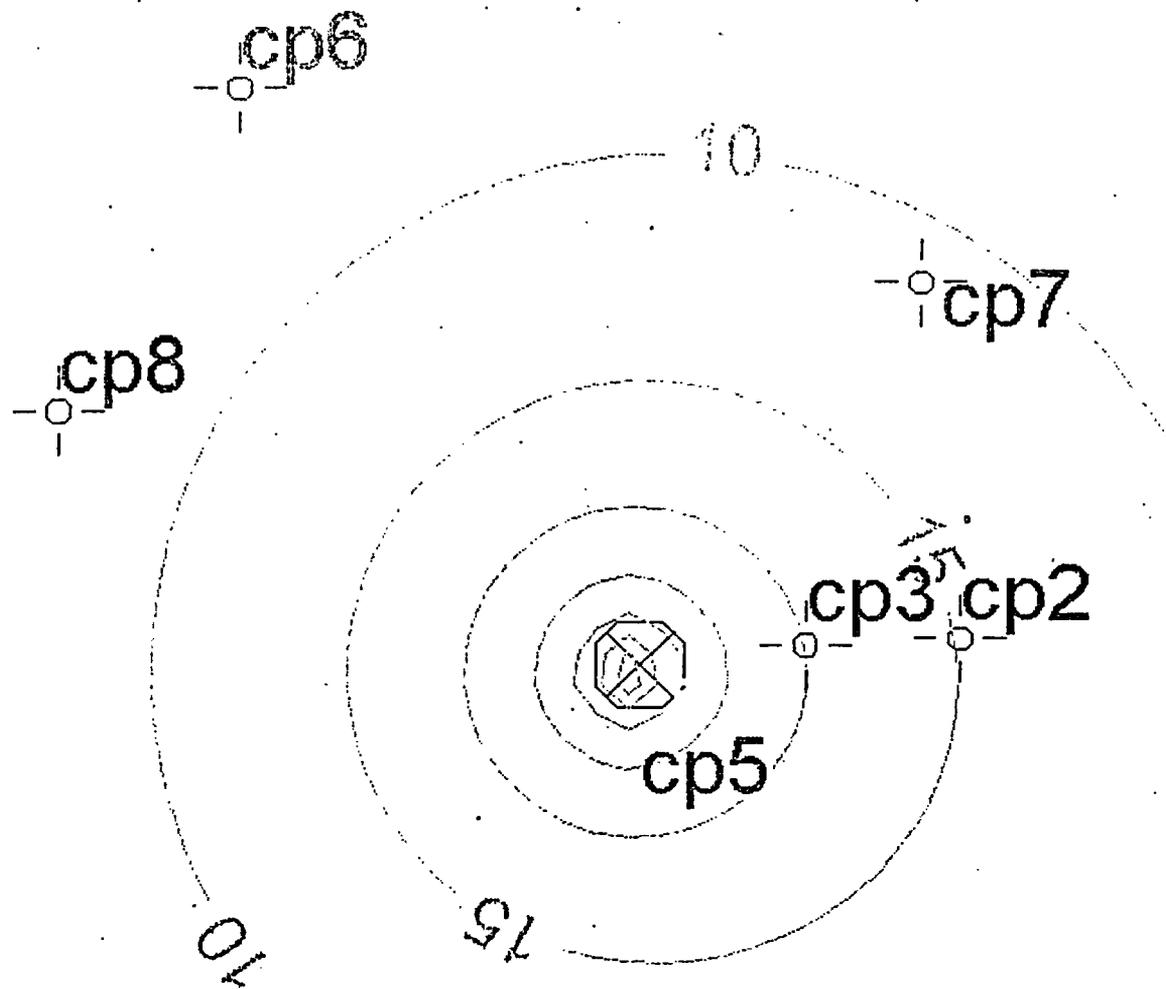


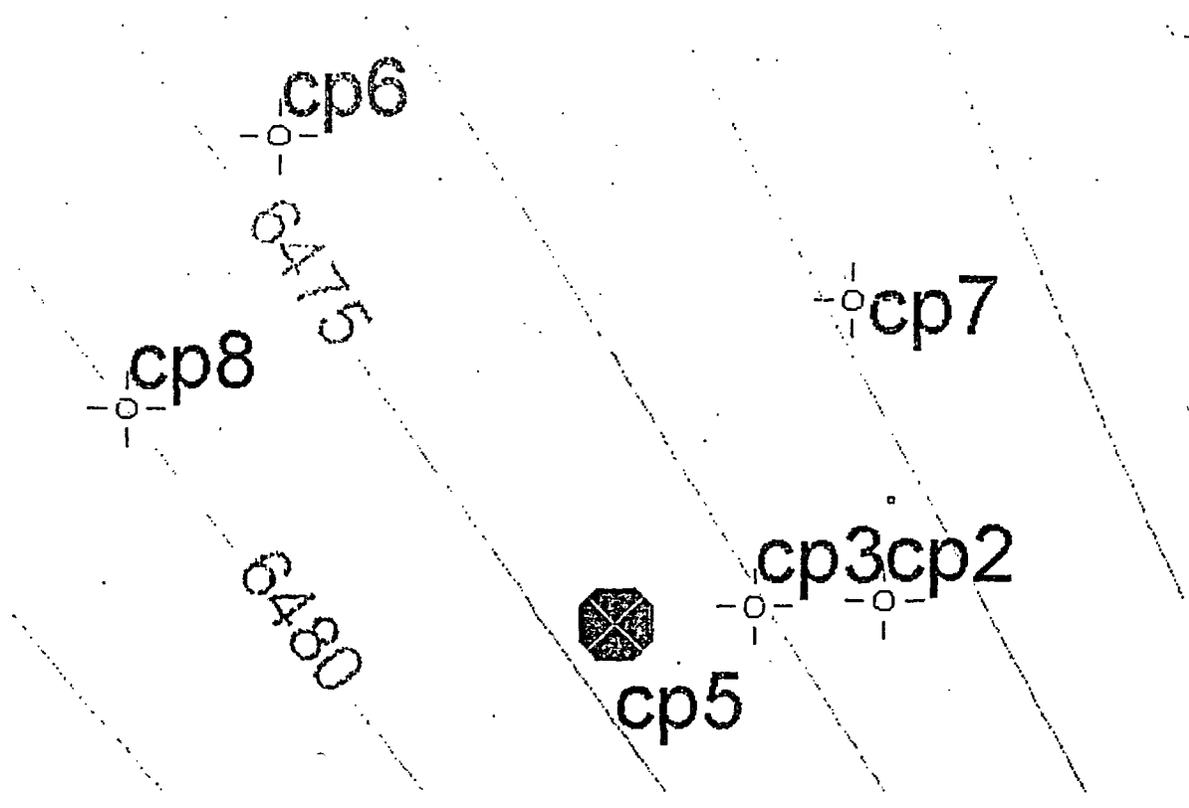
Figure 10a. Drawdown Trough Resulting from HRI Crownpoint Pump Test (Spring 1991). Note that drawdown is greater at CP8 than it is at CP7, even though it (CP8) is further from the pumping well CP5.



**Figure 10b. Inferred Anisotropy from HRI pump test (HRI's own analysis)**



**Figure 11. Drawdown (ft.) Contour Results of Homogeneous Calibration Run (which is representative of the HRI model) (SRIC\_CP\_homb.gvw). Note Poor match to Figure 10.**



**Figure 12. Hydraulic Head (ft amsl) Contour Plot of Homogeneous Calibration Run (pre-pump test) (SRIC\_CP\_homb.gvw)**

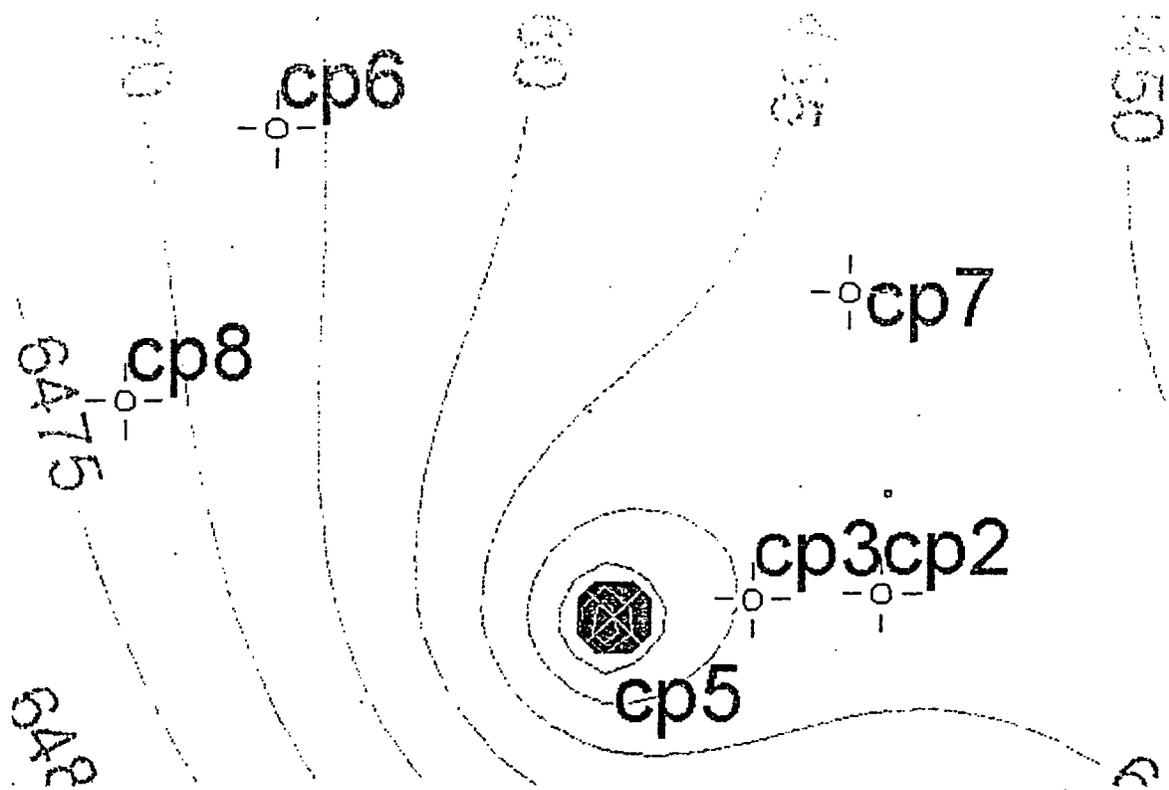
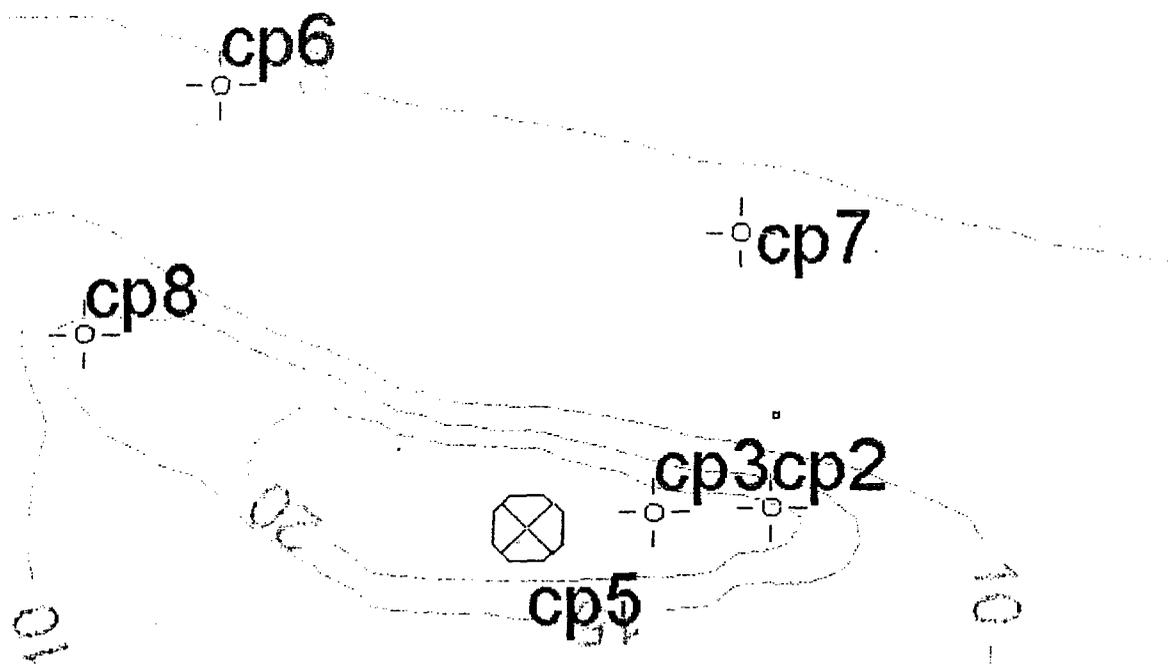
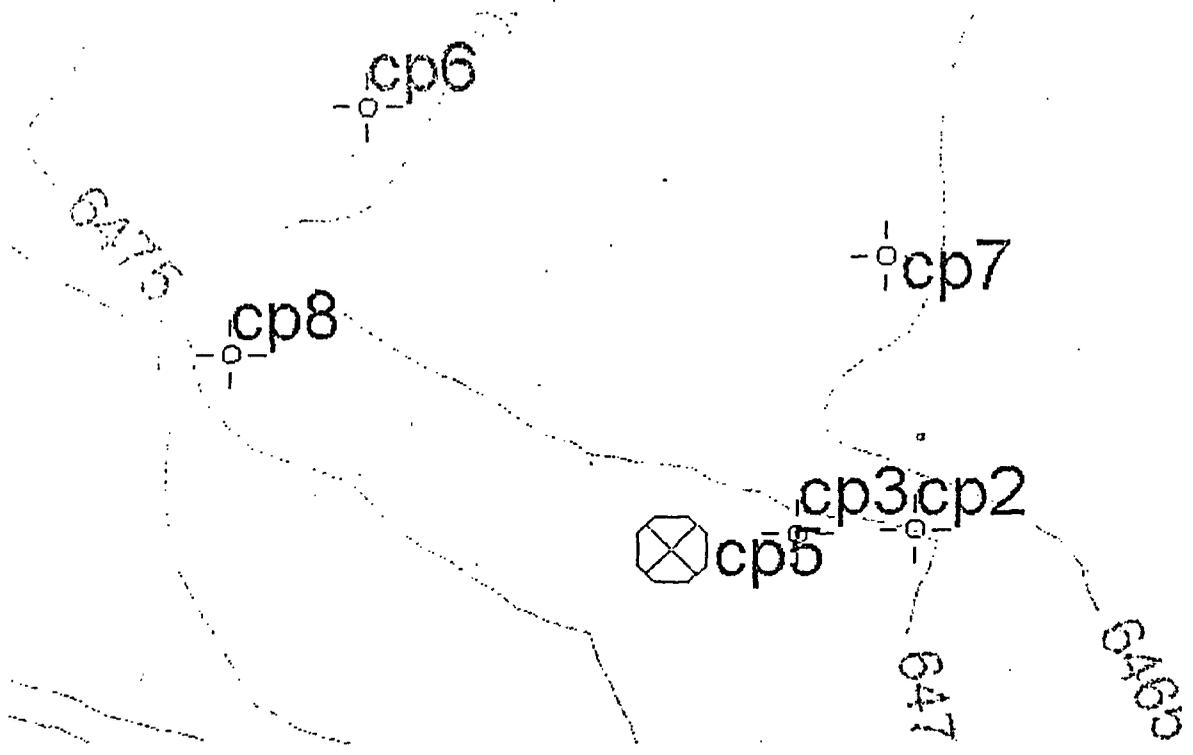


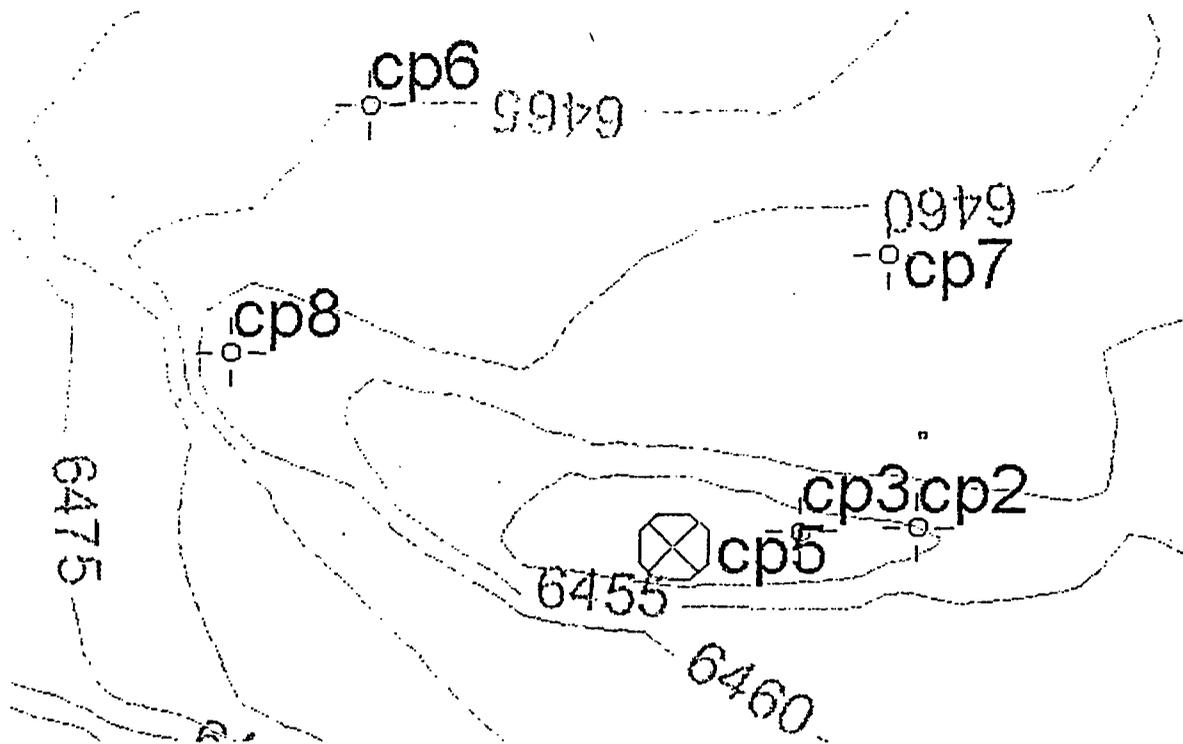
Figure 13. Hydraulic Head (ft amsl) Contour Plot of Homogeneous Calibration Run (end of pump test) (SRIC\_CP\_homb.gwv)



**Figure 14. Drawdown (ft.) Results of ENDAUM Heterogeneous Calibration Run (SRIC\_CP7b.gvw). Note good match to Figure 10.**



**Figure 15. Hydraulic Head (ft amsl) Contour Plot of ENDAUM Heterogeneous Calibration Run (pre-pump test) (SRIC\_CP7b.gww)**



**Figure 16. Hydraulic Head (ft amsl) Contour Plot of ENDAUM Heterogeneous Calibration Run (end of pump test) (SRIC\_CP7b.gww)**

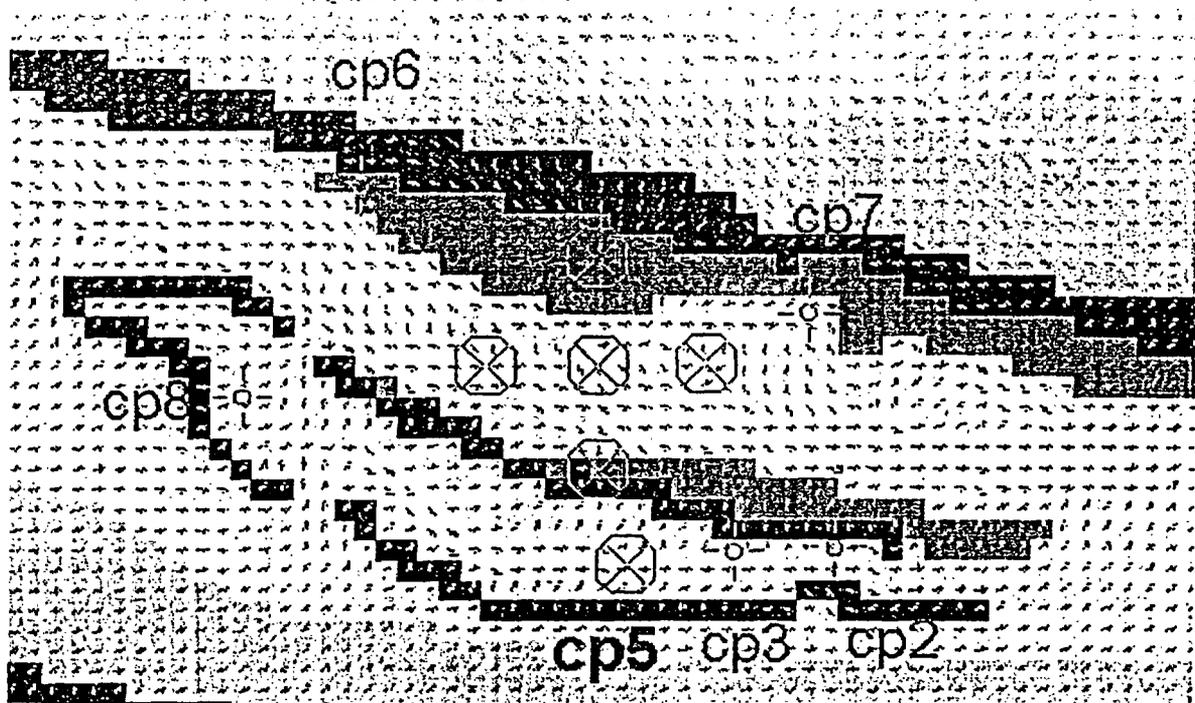
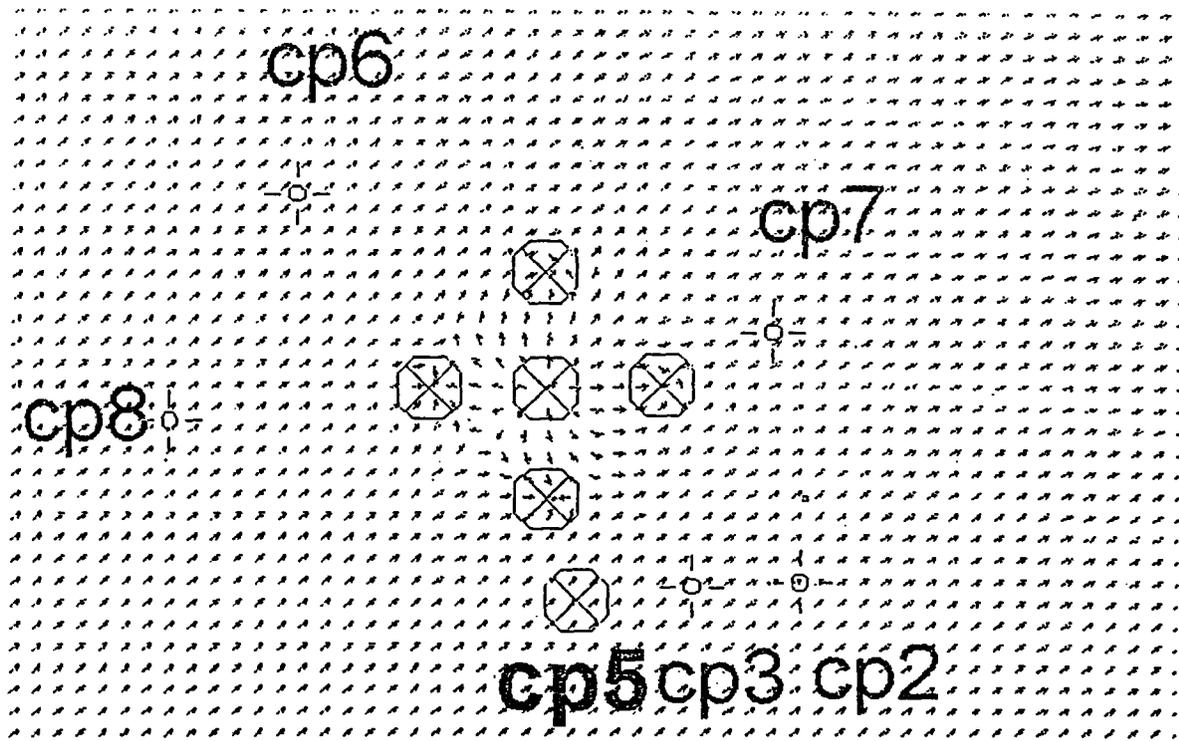
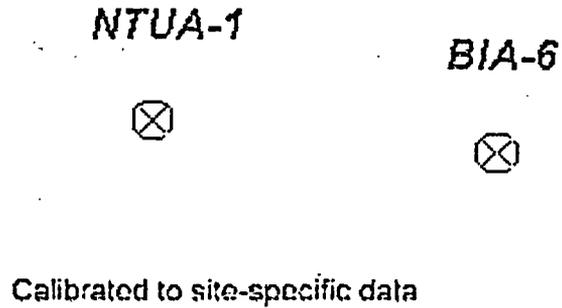
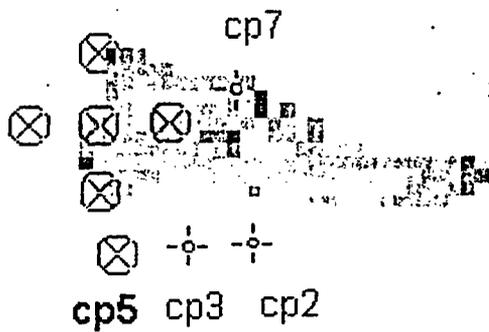


Figure 17. Representation of Mining Activity by a Single 5-Spot Pattern, With Resulting Velocity Distribution for ENDAUM Heterogeneous (Channel) Case (SRIC\_07b\_trans\_het\_min.gvw).



**Figure 18. Representation of Mining Activity by a Single 5-Spot Pattern, With Resulting Velocity Distribution for HRI Homogeneous Case**

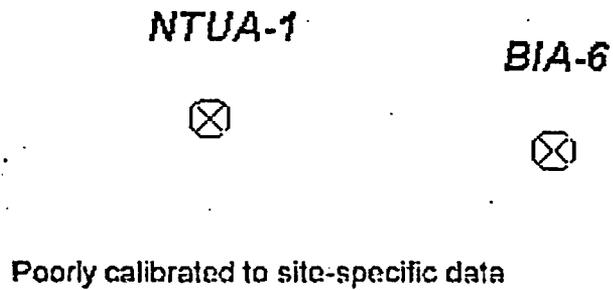
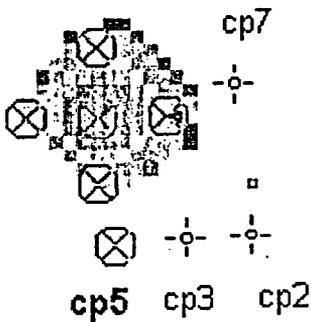
### Channel Case



Calibrated to site-specific data

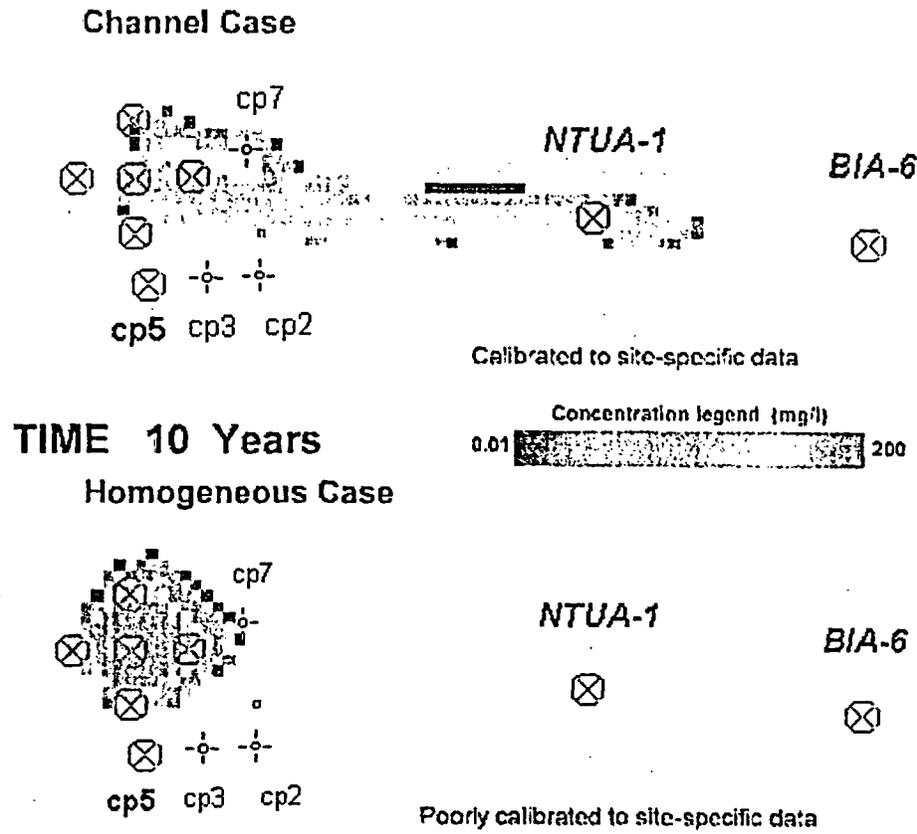
### TIME 5 Years

### Homogeneous Case



Poorly calibrated to site-specific data

Figure 19. Prediction of Crownpoint Site Plume Transport Five Years into Mining Activity for Channel (Heterogeneous) and Homogeneous Cases.



**Figure 20. Prediction of Crownpoint Site Plume Transport Ten Years into Mining Activity for Channel (Heterogeneous) and Homogeneous Cases.**

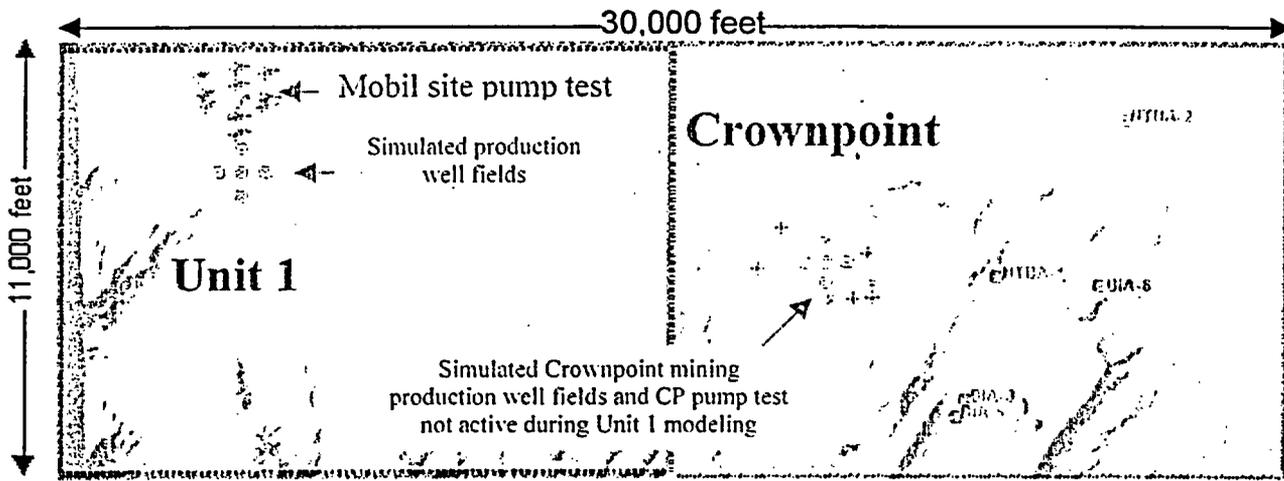


Figure 22 Unit 1 Model Layout (shaded relief placement is approximate)

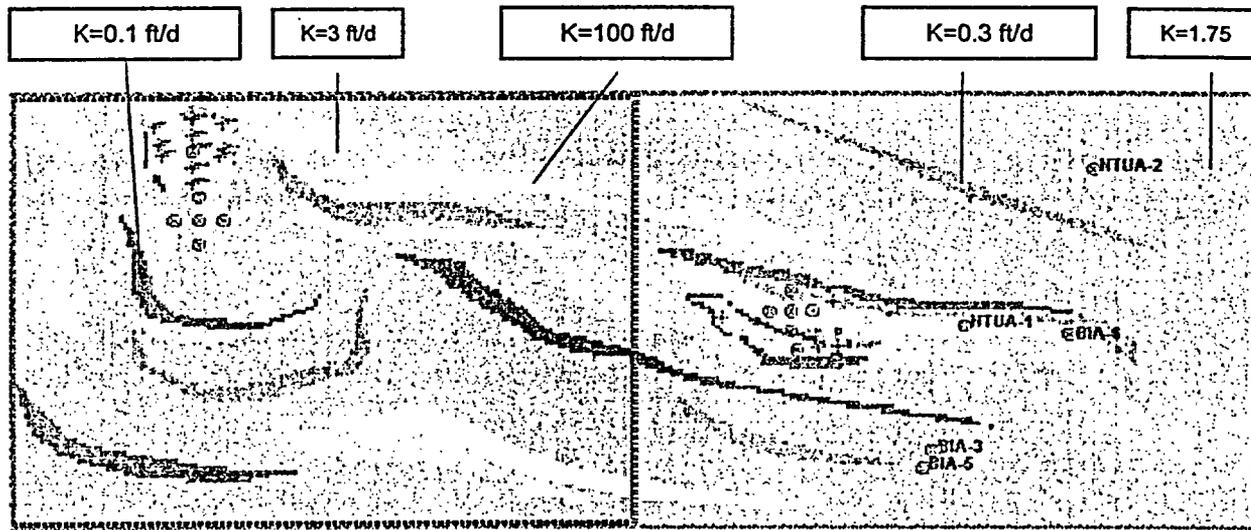


Figure 23 Hydraulic Conductivity Zonation for Unit 1 Model

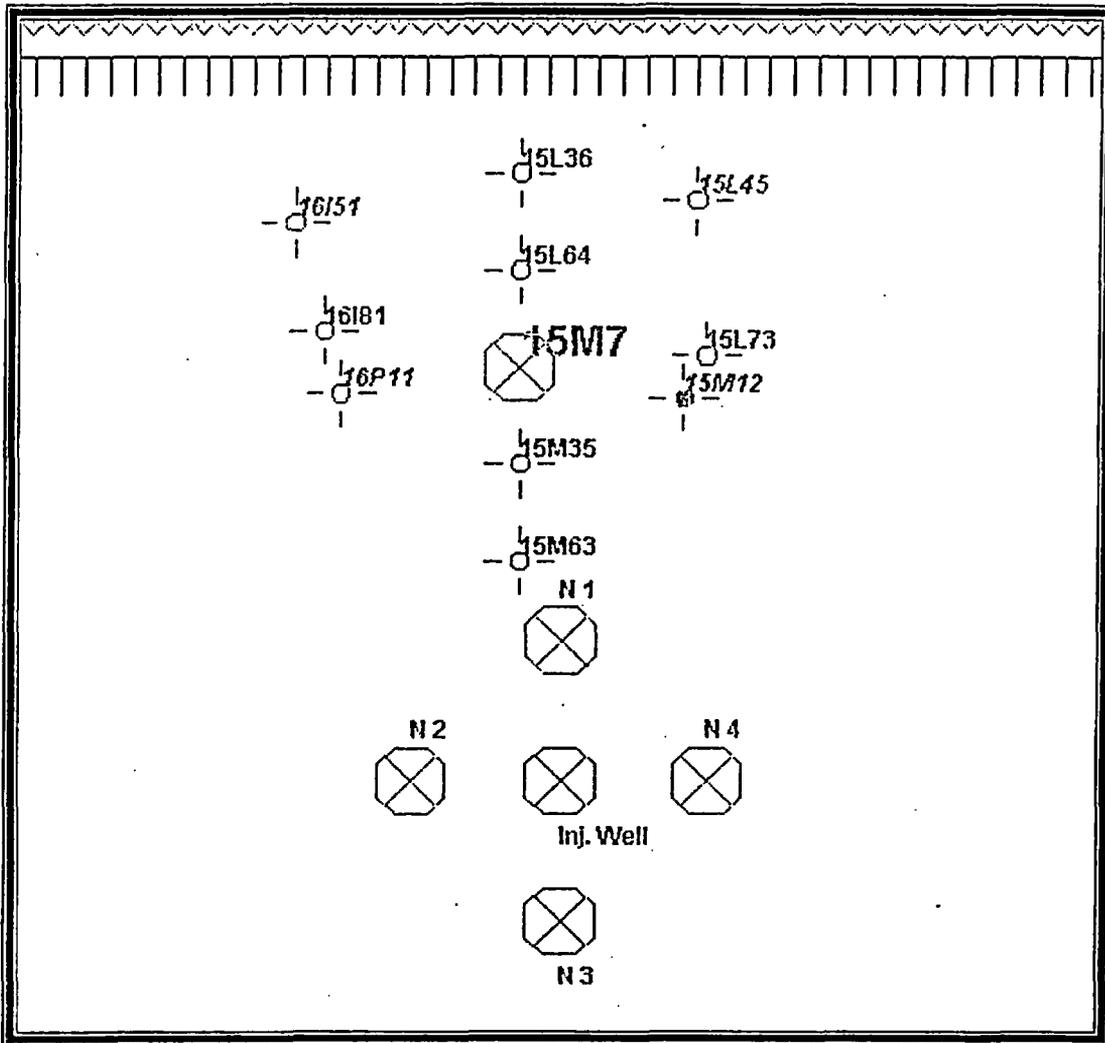
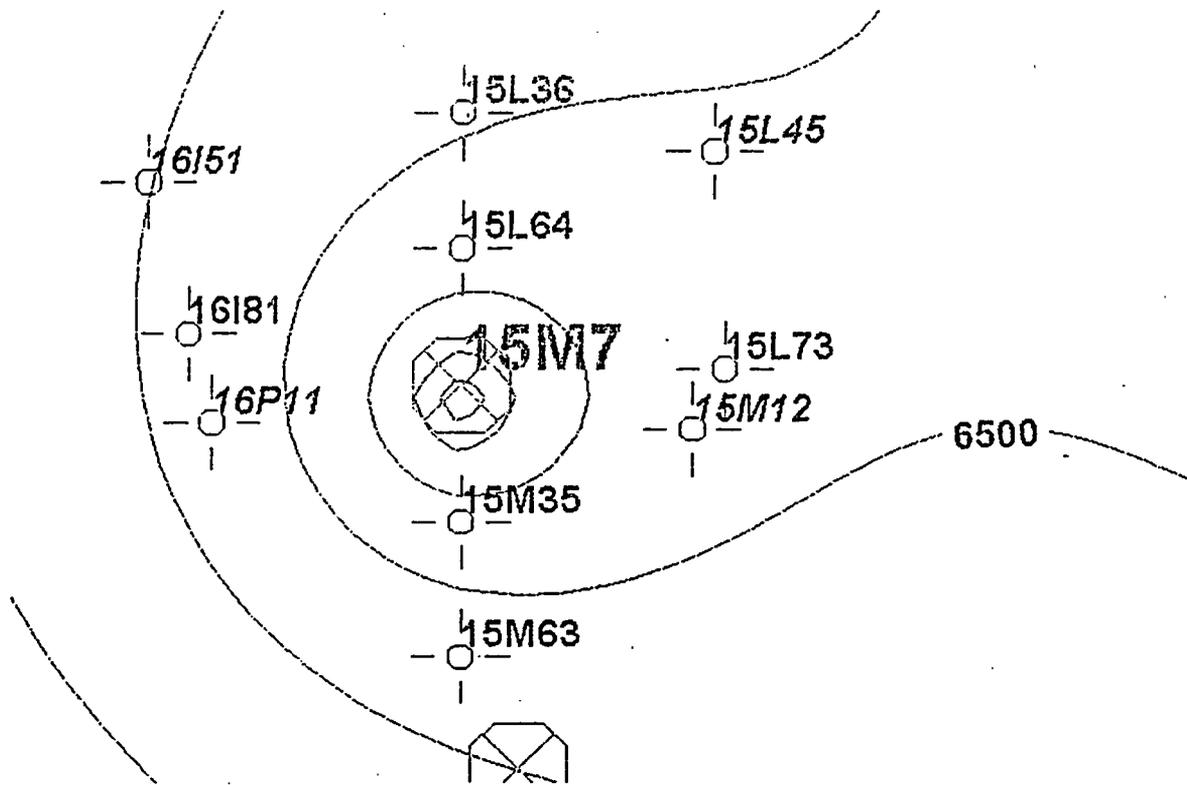


Figure 24. Detail of the Unit 1 Model Showing the Pumping Test Setup, as well as the ISL Well Setup.



**Figure 25. Results of the Pumping Test Simulations Using Homogeneous Hydraulic Conductivity (HRI's conception).**

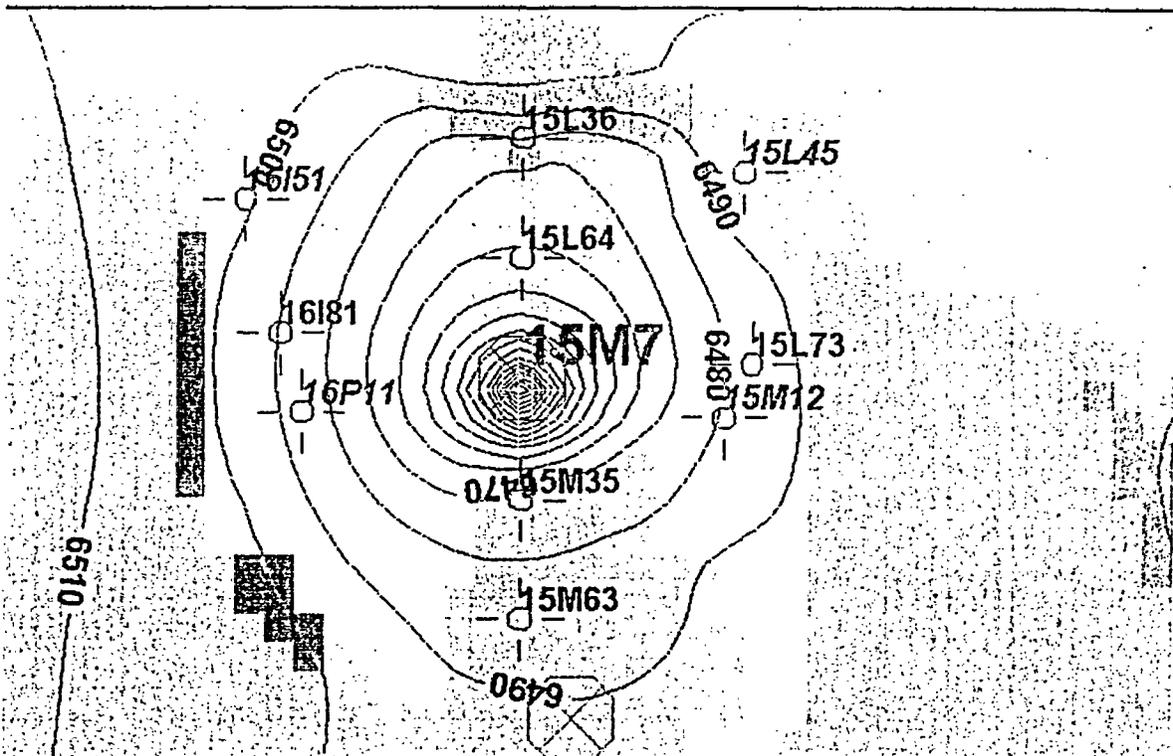


Figure 26. Detail of Results of the Pumping Test Simulations Using Heterogeneous Hydraulic Conductivity (ENDAUM's conception).

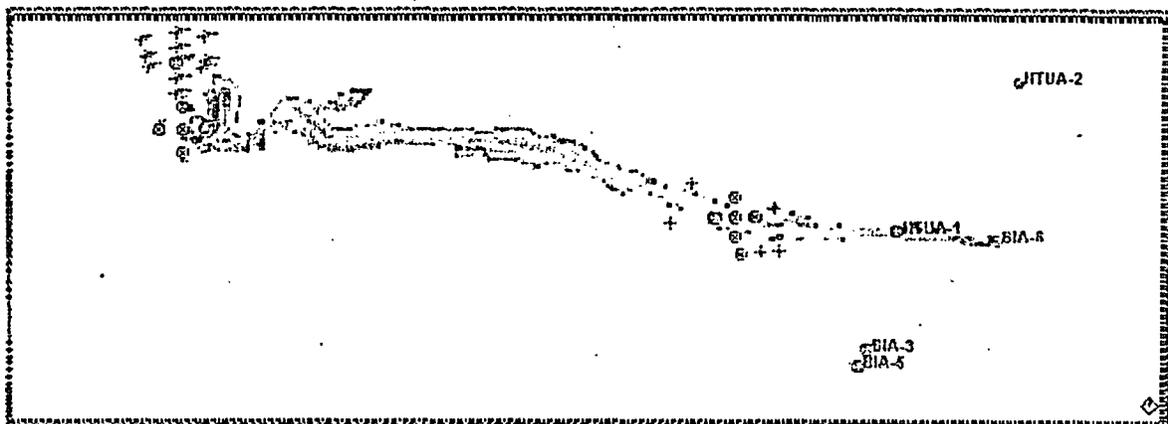
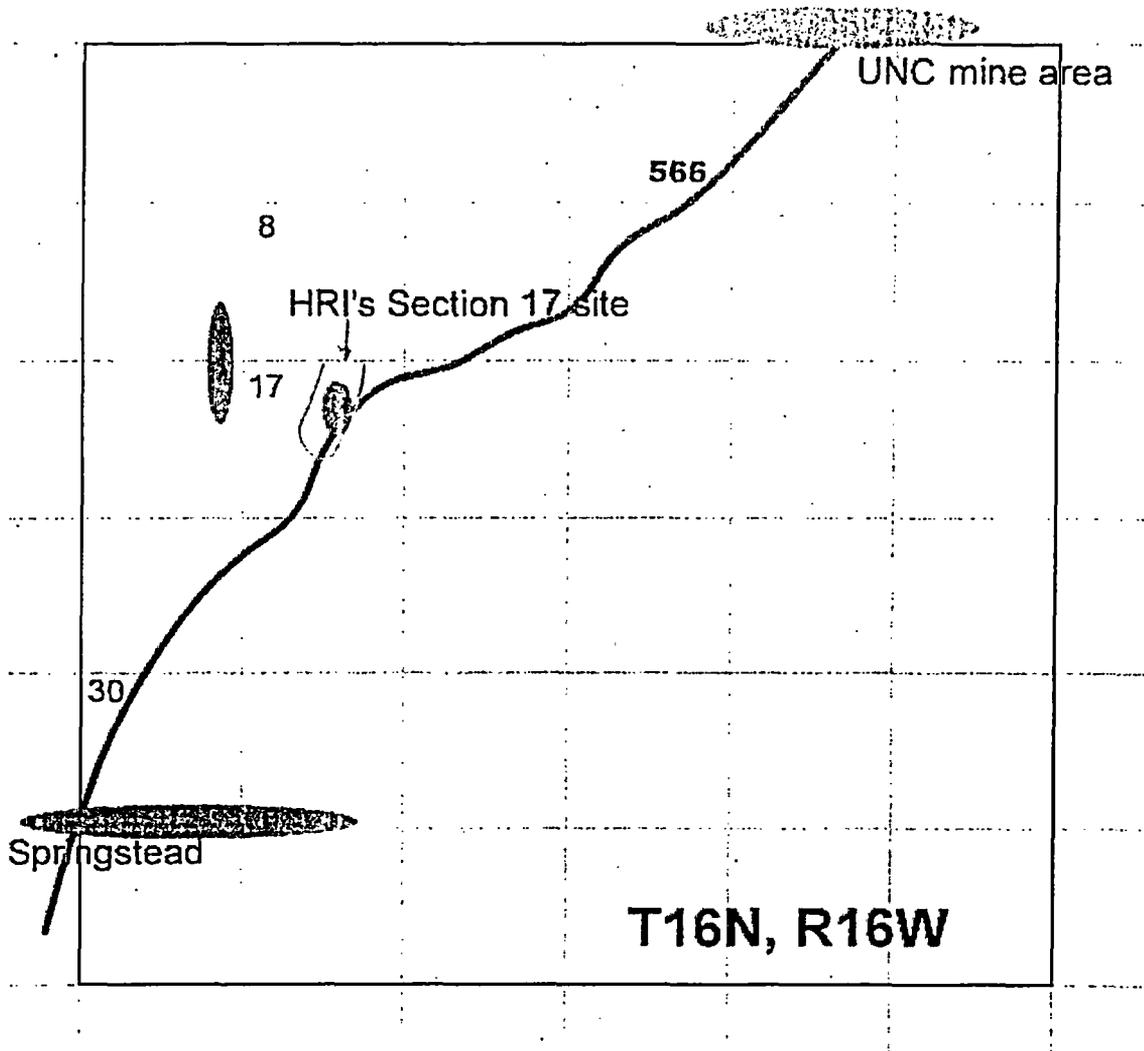
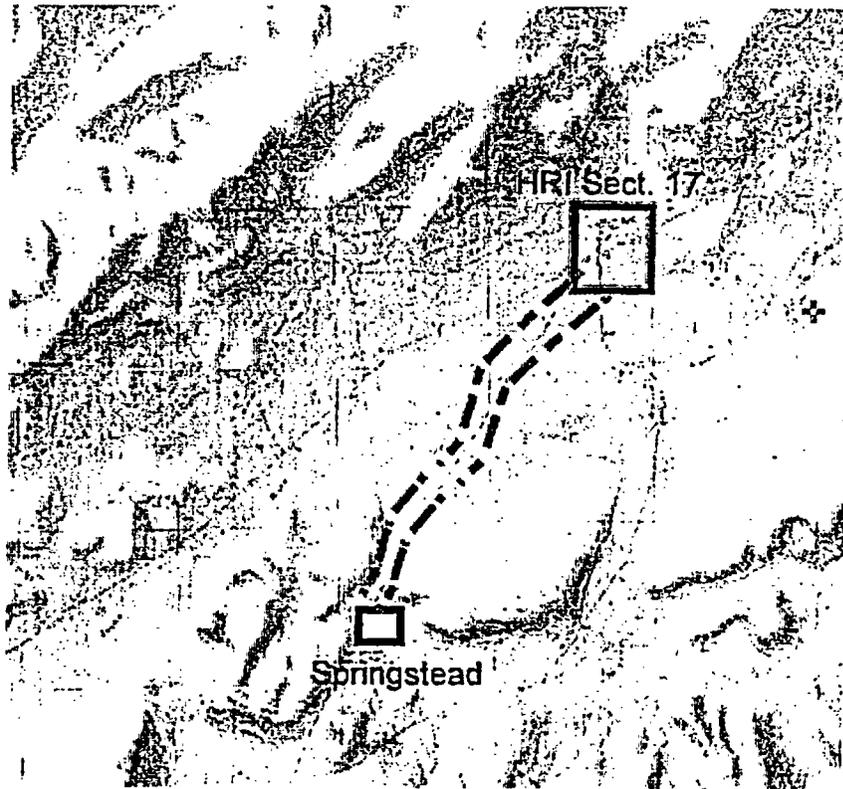


Figure 27. Results of Unit 1 Heterogeneous Case, Transport Simulations at 63 yrs since the Beginning of Operations (Simultaneous Injection and Pumping for first 27 years) (see Figure 21 for concentration color profile legend)



**Figure 28. Areas Surrounding and Including Section 17 where Recapture is Documented to be 'Patchy' or Missing (solid ovals).**



**Figure 29. Physiographic View of Area Within and Surrounding HRI Section 17 and the Proposed Springstead Community. Section lines indicate scale (each square is one square mile in area).**

**EXHIBIT C**

**EXHIBIT D**

New Mexico Office of the State Engineer  
Well Reports and Downloads

Township: 16N Range: 16W Sections: 30

NAD27 X: Y: Zone: Search Radius:

County: MK Basin: Number: Suffix:

Owner Name: (First) (Last)  Non-Domestic  Domestic  All

Well / Surface Data Report Avg Depth to Water Report Water Column Report  
Clear Form WATERS Menu Help

WELL / SURFACE DATA REPORT 12/14/2004

DB File Nbr	(acre ft per annum) Use	Diversion	Owner	Well Number	Source	Tws	Rng	Sec	q	q	q	X Y are in Feet Zone	X
G 01100	COM	51	WILLIAM H. AUBREY	G 01100 S-2	Shallow	16N	16W	30	1	1	2		

Record Count: 1

Remainder of Record that could not be printed from web page screen:

UTM Zone	Easting	Northing	Start Date	Finish Date	Depth Well (in feet)
13	175770	3944666	12/31/1968	12/31/1968	500

**EXHIBIT E**

[Fwd: FYI, with regard to a charac...rs of your opinion on an ISL mine]

**Subject:** [Fwd: FYI, with regard to a characterization by NRC and others of your opinion on an ISL mine]  
**Date:** Wed, 03 Mar 1999 19:57:13 -0700  
**From:** michael wallace <mwallace@thuntek.net>  
**Reply-To:** mgw@anacrolith.com  
**Organization:** michael wallace  
**To:** "nmelc@nets.com" <nmelc@nets.com>, SRIC <srlic@igc.org>



please forward this important email to Johanna Matanich and Chris Shuey respectively at the earliest possible opportunity.  
thank you,  
Mike Wallace

---

**Subject:** Re: FYI, with regard to a characterization by NRC and others of your opinion on an ISL mine  
**Date:** Wed, 3 Mar 1999 12:10:15 -0700  
**From:** "Shlom P. Neuman" <neuman@hwr.arizona.edu>  
**To:** <mgw@anacrolith.com>  
**CC:** "Tom Nicholson" <tjn@nrc.gov>

Dear Michael:

It was good to hear from you, and I want to thank you for your candid note regarding the uranium ISL licensing issues associated with HRI's intentions in New Mexico's San Juan Basin, and the lingering controversy regarding my position on these issues.

Allow me to clarify some points regarding my "position" on these issues:

1. I have never formulated either a formal or an informal position regarding the above site or issues.
2. In the context of a generic research project on conceptual hydrogeologic models, on which I am working under the auspices of the US Nuclear Regulatory Commission (NRC), I reviewed NUREG-1508 titled Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico. The purpose of my review was merely to use this case as an example of a hydrogeologic framework, and its conceptual modeling, by the NRC.
3. My opinion about the manner in which hydrogeology at the site is conceptualized in NUREG- 1508 is summarized in overheads I presented to the NRC staff at the agency's headquarters in Rockville, MD, on January 29, 1998. My opinion is amplified in an internal letter report I submitted to the NRC, concerning my research for the agency, at about the same time.
4. In preparing my opinion, I was completely unaware of any controversy or litigation concerning the site.
5. To date, I have not reviewed any additional material concerning the site.
6. Based on the information in NUREG-1508, I stand behind every statement that I made in my talk to the NRC staff on January 29, 1998, concerning the site.
7. On march 19, 1998, I participated in a teleconference concerning my above opinion about the hydrogeologic conceptual framework for the site with NRC staff. This teleconference has not changed my opinion about hydrogeologic conceptualization of the site in any way.
8. Any statement or statements made by the NRC concerning opinions that I allegedly voiced during this teleconference are those of the agency, not mine. I have never been given a chance to review and/or comment on such statements.
9. In particular, an NRC memo by Joseph J. Holonich, Chief of the Uranium Recovery Branch, addressed to Peter B. Bloch, Presiding Officer of the Atomic Safety and Licensing Board, dated April 20, 1998, misrepresented my association with the NRC and my opinions about the site.

[Fwd: FYI, with regard to a charac...rs of your opinion on an ISL mine]

Feel free to bring these points to the attention of anyone concerned with this matter.

Best regards,

Shlomo Neuman



PROD. 3 UTIL. PAC. 40-8968-ML

UNITED STATES  
NUCLEAR REGULATORY COMMISSION

WASHINGTON, D.C. 20555-0001

February 27, 1998

DOCKETED  
USNRC

98 MAR -4 AIG :47

MEMORANDUM TO: B. Paul Cotter, Presiding Officer  
Atomic Safety and Licensing Board

FROM: Joseph J. Holonich, Chief  
Uranium Recovery Branch  
Division of Waste Management  
Office of Nuclear Material Safety  
and Safeguards

OFF-  
*Joseph J. Holonich*  
RECEIVED

SERVED MAR -4 1998

SUBJECT: NEW INFORMATION POTENTIALLY RELEVANT AND MATERIAL TO  
THE PROCEEDING IN THE MATTER OF HYDRO RESOURCES, INC.  
(ASLBP NO. 95-706-01-ML)

Pursuant to Commission Policy on Notification to Licensing Boards of new relevant and material information, the attached document is considered potentially relevant and material to the Hydro Resources, Inc. (HRI) proceeding, and is forwarded herewith. This information consists of a set of slides developed by Professor Shlomo P. Neuman, Department of Hydrology and Water Resources, University of Arizona. Professor Neuman is the Principal Investigator on a Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES) funded research project entitled "Evaluating and Testing Conceptual Ground-Water Flow and Transport Models." In that role, Professor Neuman made an oral presentation to the NRC staff on January 29, 1998, (this was not a public meeting, but rather an internal working meeting with the NRC staff). His presentation focused on his new generic research project dealing with evaluation and testing of conceptual ground-water flow and transport models. The purpose of Professor Neuman's RES-funded research is to develop a methodology which will have broad application to many radioactive waste problems. Prior to his presentation, Professor Neuman requested that general information be provided to him as background material to acquaint him with NRC issues related to his research focus, and to familiarize him with uranium in situ leach mining. A copy of NUREG-1508, "Final Environmental Impact Statement for the Crownpoint In Situ Leach Mining Project," (FEIS) was provided to him.

Professor Neuman prepared a series of talking points in the form of view graphs to discuss his initial research strategies and to facilitate interaction with the NRC staff. The attached package is from the background material that he used during the meeting. These particular view graphs were neither shown nor discussed in the meeting. In particular, the detailed information and conclusion on the last page of the package was not presented or discussed with the staff. The Office of Nuclear Material Safety and Safeguards/Division of Waste Management (NMSS/DWM) staff working on the Crownpoint Project were provided copies of the view

CONTACT: Robert Carlson, NMSS/DWM  
(301) 415-8165

graphs, but have not discussed Professor Neuman's observations and conclusion with him. Professor Neuman was not requested to formally review or comment on the FEIS, as this was outside the scope of his original work. His presentation discussed research strategies in the context of NRC licensing applications, using the limited, publicly available information provided to him on site decommissioning management plan reviews and in situ leach uranium mining, and his extensive expertise in high-level radioactive waste.

The information in the attached slides is considered potentially relevant and material to the subject proceeding because they provide Dr. Neuman's view on the FEIS regarding the HRI license application. Many of the questions raised in Professor Neuman's slides were also raised by the petitioners in their petitions for leave to intervene. Essentially, the staff's understanding of the slides is that Professor Neuman believes that the FEIS needed to consider a number of other factors related to the pumping test used to determine the confinement of the mining aquifer. The areas where Professor Neuman discussed that additional information on pumping tests needed to be considered in the FEIS are given on the last page of his slides. In addition, Professor Neuman concludes that the conceptual framework of the FEIS is indefensible.

Because the NMSS/DWM staff was unable to attend Professor Neuman's briefing, he did not present the information in the attachment. Instead, the slides were given to the NMSS/DWM staff as information copies only. The staff has done an evaluation of the information, and is able to provide an assessment of it based solely on the content of the slides. If the staff had received a presentation of this work, it may have had better insight into what Professor Neuman meant, and could provide the best possible analysis of the slides. Based on its review of just the information presented in Professor Neuman's slides, the staff is in general agreement with the broad, individual points raised. However, the staff considers that Professor Neuman did not have a complete understanding of all information evaluated by the staff to determine the specific acceptability of HRI's application, since his review was limited to only the FEIS. Information not considered by Professor Neuman included: 1) the application filed by HRI containing extensive data used as the basis for the staff's review; 2) results from other licensing reviews conducted by staff and Agreement States; 3) experience from operating in situ leach facilities at other licensed sites; and 4) other data such as geologic borings used to determine the stratification of the mining units.

As mentioned above, although the staff agrees with the general points in Professor Neuman's summary slide that appear to fault pump tests that were used to demonstrate non-hydraulic interconnection between the Dakota Sandstone and Westwater Canyon aquifers at the Crownpoint site, the staff does not agree with Professor Neuman's overall conclusion that the FEIS is seriously technically flawed and indefensible. This is based in part on his lack of background information as enumerated above, and the fact that pumping tests conducted at the Crownpoint site were not used by the staff to make its conclusion on vertical confinement as summarized in the FEIS. Instead, the staff based its decision on the following information (See FEIS Section 4.3.1.1, pages 4-42 and 4-43):

- (1) The large thickness of the confining unit between the Westwater Canyon aquifer and the overlying Dakota Sandstone Aquifer;

- (2) The significant differences in water levels between the Dakota Sandstone aquifer and the Westwater Canyon aquifer, indicating the two aquifers are not interconnected;
- (3) The possession of borehole sealing records by HRI, which increases the confidence that the holes were sealed correctly and should not leak during ISL mining activities;
- (4) The observation that the Crownpoint mine shafts are lined with steel and grouted to the surface and so that they do not present an avenue for the vertical movement of groundwater;
- (5) The lack of significant displacement in the Westwater sands indicating that there is little potential for faults to act as vertical pathways;
- (6) and the commitments by the applicant to: (a) perform groundwater pump tests to determine if overlying confining units are adequate confining layers prior to injection of lixiviant in a well field; (b) monitor overlying aquifers; and (c) conduct well integrity tests.

The staff recognizes Professor Neuman's experience and contributions to the advancement of ground-water science and does not dispute his credentials. However, the staff is not clear on the specific basis Professor Neuman used to reach the conclusion of FEIS indefensibility presented in the slides, given the staff's understanding that other pertinent information was not reviewed by Professor Neuman. Therefore, the staff plans to discuss Professor Neuman's concerns with him to gain a better understanding of his issues, and to ensure he has the full breadth of information that the staff had to arrive at its conclusion.

Docket Number 40-8968-ML

Attachment: As stated

**ATTACHMENT**

# "Hydrogeologic Conceptualization for Environmental Safety Assessment: Case Studies and Steps Toward a Strategy"

Speaker: Professor Shlomo P. Neuman  
Department of Hydrology & Water Resources  
The University of Arizona

Time: 10:30 a.m. - 3:00 p.m., January 29, 1998

Room: T8-A1

## Abstract:

Conceptual/mathematical hydrogeologic models of subsurface flow and transport are introduced and analyzed through case studies of: a decommissioning site in Ohio; a uranium solution mining project in New Mexico; the unsaturated and saturated zones surrounding potential high-level nuclear waste repositories such as the Whiteshell research area in Manitoba, Canada. These cases illustrate the complexity of hydrogeologic conceptualization, its numerous pitfalls and potential to constitute a major source of uncertainty in assessing the expected safety performance of such sites. These cases also demonstrate the need for a well-articulated and defined strategy that one could follow in developing and evaluating conceptual/mathematical flow and transport models in the context of performance assessment. Some key elements of such a strategy are outlined in a preliminary fashion with emphasis on the postulation of alternative conceptual models, the testing of such models and the process of discriminating among them. The latter are illustrated qualitatively and quantitatively via case studies concerning: the large apparent hydraulic gradient at a potential high-level waste repository site; interaction between fractures and matrix during unsaturated flow and transport at that site; type-curve interpretation and geostatistical analysis of single- and cross-hole air-permeabilities at the Apache Leap Research Site in Arizona; inverse modeling of pumping tests in fractured crystalline rock at Chalk River in Ontario, Canada; and inverse modeling of ground-water flow in the semiarid evaporitic basin of Los Monegros, Spain. Additional relevant examples can be found, among others, in reports of the INTRAVAL Project.

Contact: T. Nicholson, WMB/DRA/RES at (301) 415-6268 if you have any questions.

---

---

# **Final Environmental Impact Statement**

to Construct and Operate the  
Crownpoint Uranium Solution Mining Project,  
Crownpoint, New Mexico

Docket No. 40-8968  
Hydro Resources, Inc.

---

---

Manuscript Completed: February 1997  
Date Published: February 1997

**Division of Waste Management  
Office of Nuclear Material Safety and Safeguards  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555-0001**

**in Cooperation With**

**Albuquerque District  
U.S. Bureau of Land Management  
Albuquerque, New Mexico 87107**

**Navajo Area Office  
U.S. Bureau of Indian Affairs  
Gallup, New Mexico 83701**



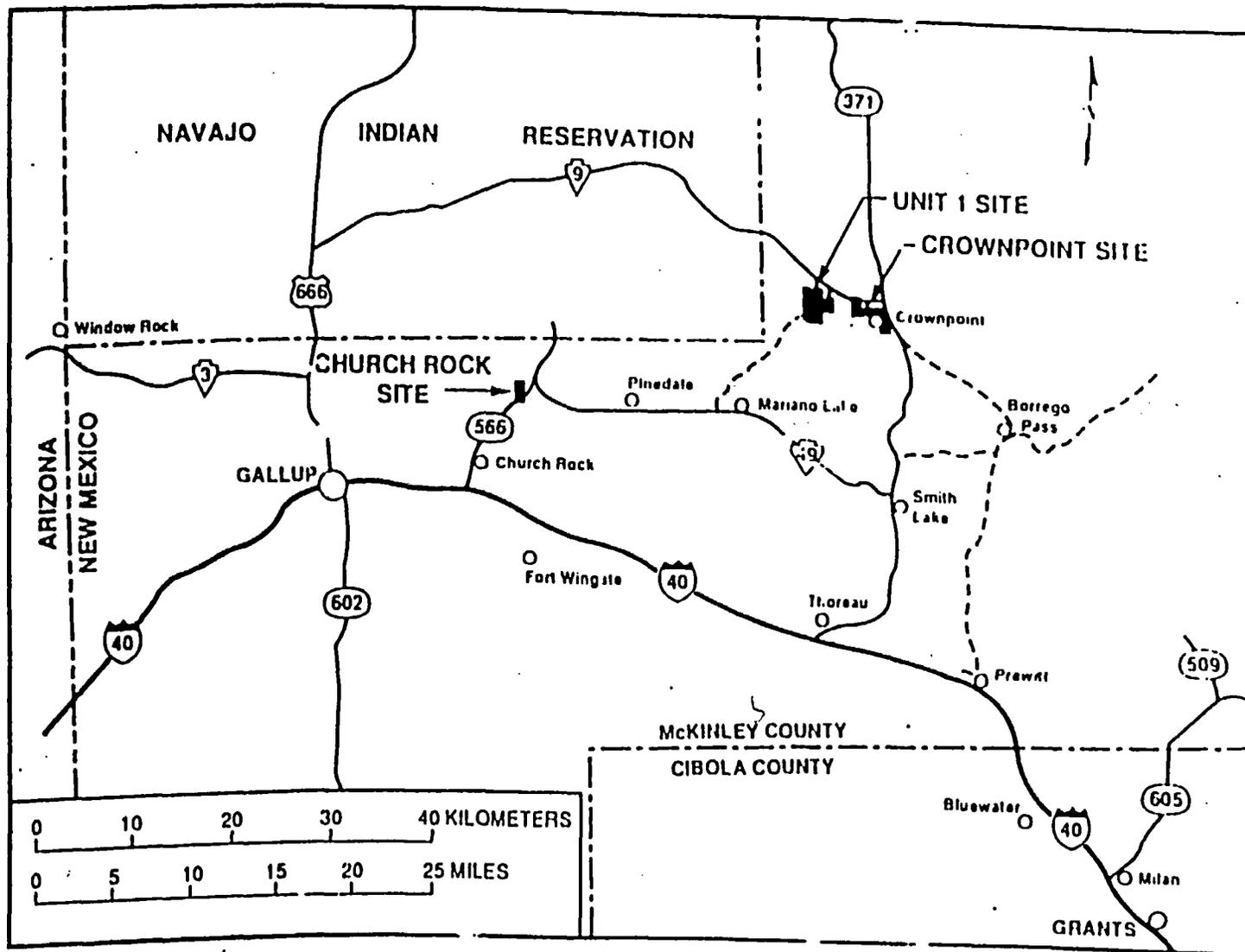


Figure 1.1. Regional index map of west-central New Mexico and the project site locations.

- Proposal by Hydro Resources, Inc. (HRI) to conduct in-situ leach (ISL) uranium mining in Westwater Canyon aquifer.
- Aquifer restoration via sweep (pumping with treatment) and permeate injection, balanced so as to maintain flow toward mining center.
- If evaporation pond capacity is exceeded consider surface application/discharge or deep injection into Abo/Yeso, TDS > 10,000 mg/L.
- Wells to be plugged/abandoned, facilities decontaminated/decommissioned, solid waste removed to licensed disposal facility, site restored and released for unrestricted use.
- FEIS evaluates 4 alternatives: as proposed; alternative combinations of sites and/or liquid waste disposal methods; as proposed with additional mitigation measures; no action.
- The NRC staff concludes that potential significant impacts of proposed project can be mitigated and recommends licensing subject to specified requirements/recommendations.

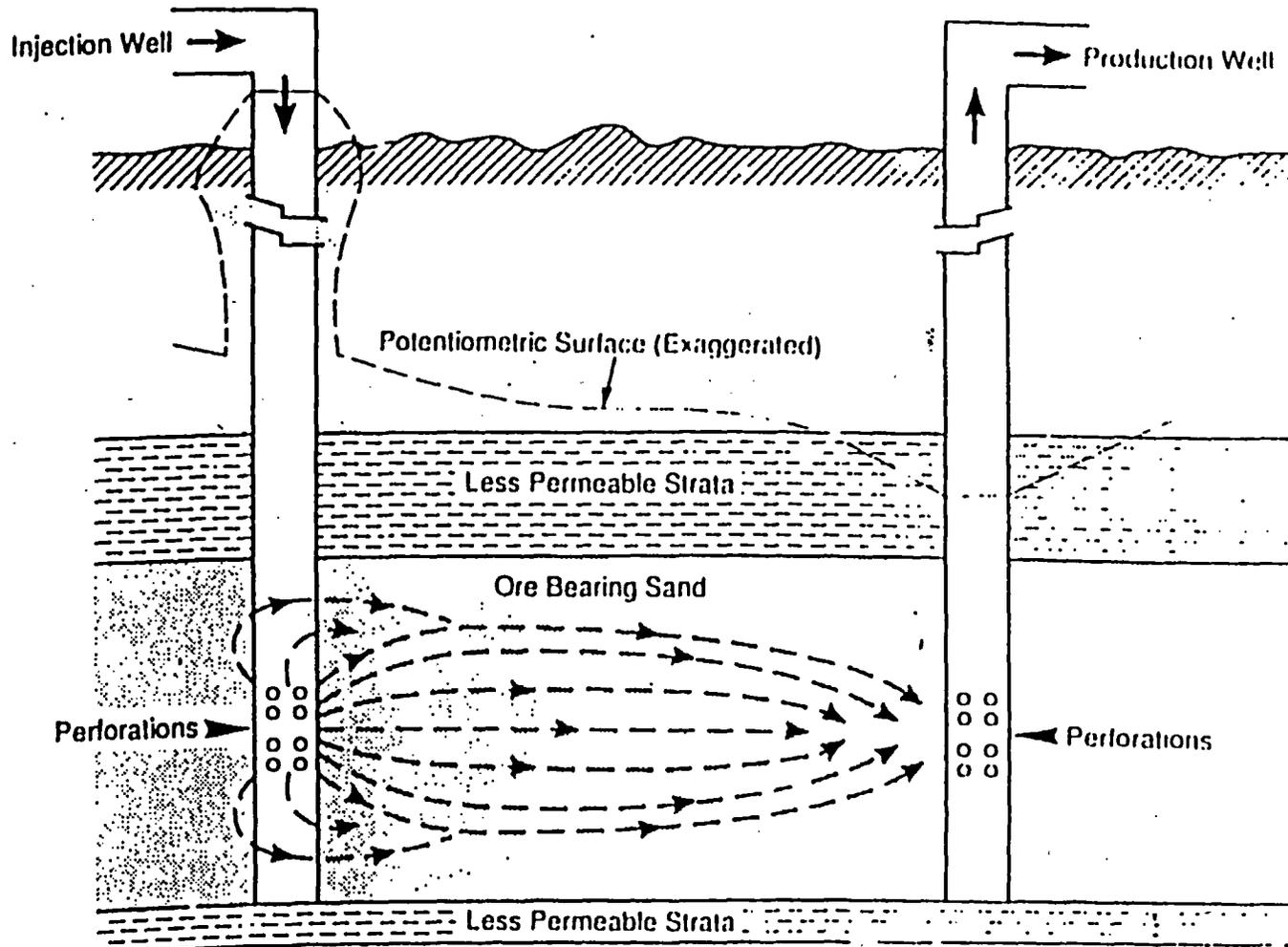


Figure 2.4. Schematic cross-section illustrating ore-zone geology and lixiviant migration from an injection well to a production well.

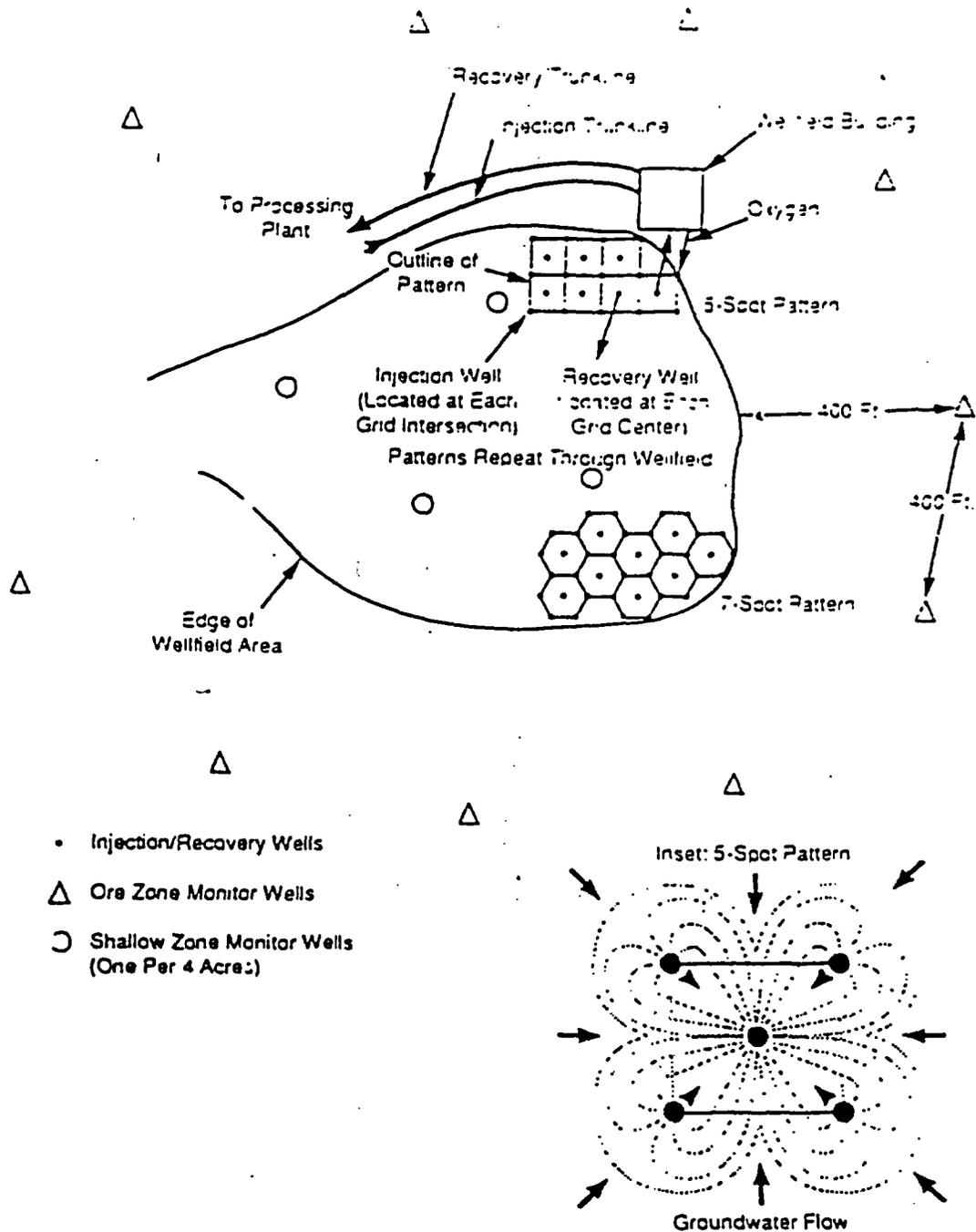


Figure 2.1. Schematic diagram of a well field showing injection/production well patterns, monitor wells, manifold building, and pipelines.

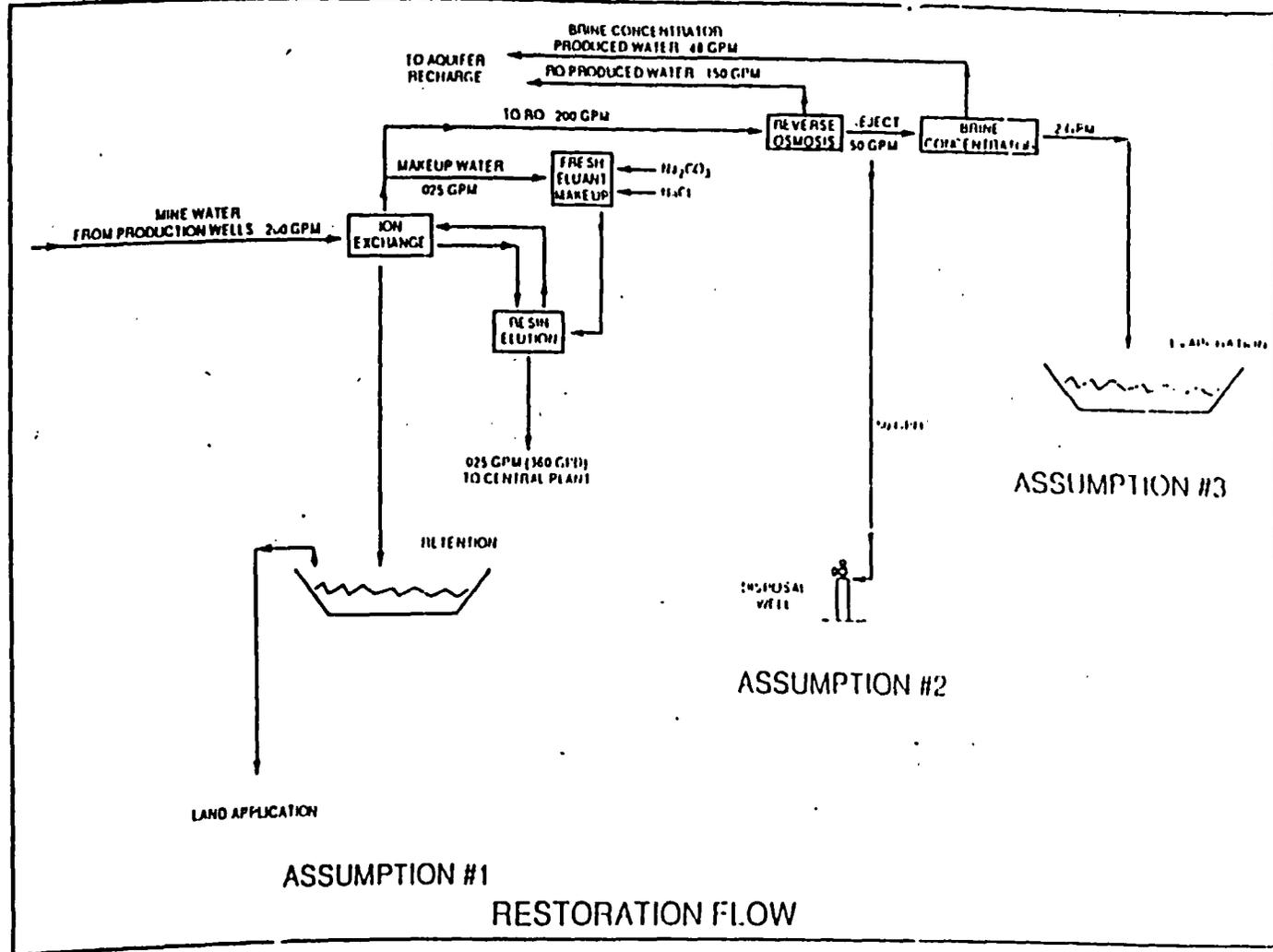


Figure 2.7. Schematic flow diagram and approximate flow rates of restoration wastewater treatment systems.

## Geology/Hydrogeology

- Westwater Canyon is high-quality regional artesian aquifer of interbedded sandstone, claystone, mudstone.
- Uranium as carbonaceous pore filling/coating in sandstone units; ore bodies several hundred to a thousand feet long parallel to strike.
- At Unit 1 & Crownpoint, Westwater Canyon is 72 - 105 m thick at depth 560 m (at Church Rock its depth is 140 - 230 m); total length of ore bodies exceeds 8 km, width 290 - 760 m.
- It is overlain at by Brushy Basin Member (locally 20 - 35 m of shale or claystone interbedded with sandstone lenses) and underlain by Recapture Member (75 - 80 m).
- Extensive mine workings at Church Rock; believed not to extend beyond boundaries of proposed solution mining area.
- Heads in overlying Dakota Sandstone aquifer are higher than in Westwater Canyon.
- Local faults have minor offsets.

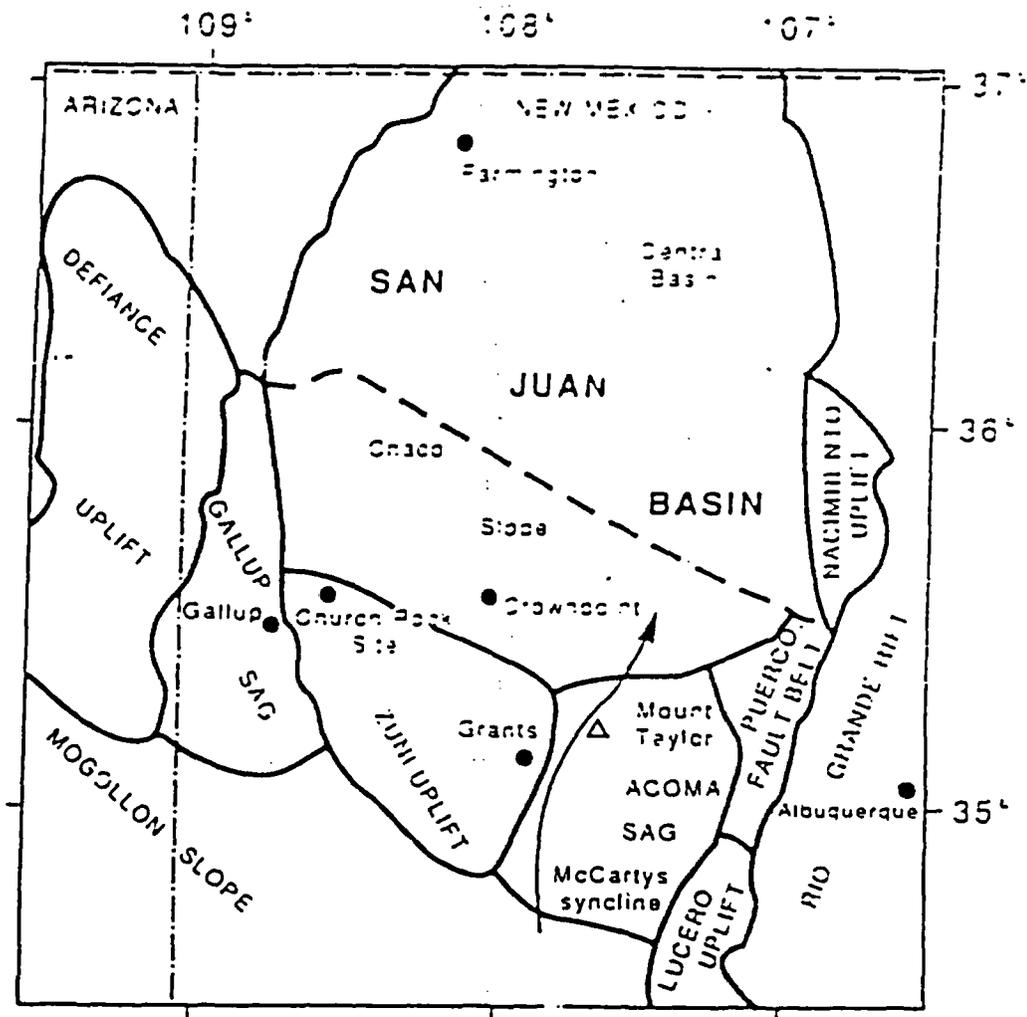


Figure 3.2. Structural setting of the San Juan Basin. Source: Kelley 1963; Kelley and Clinton 1960.

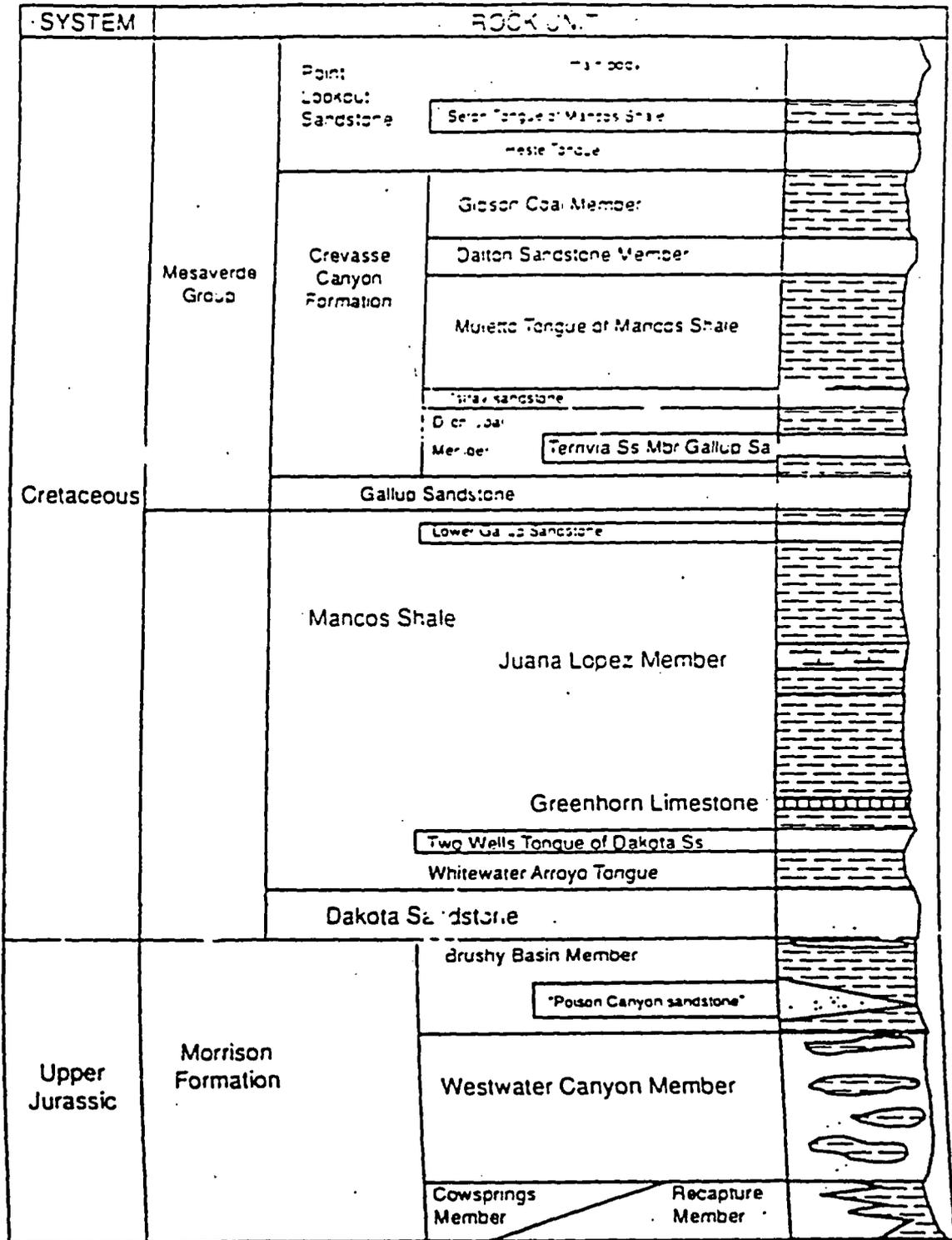


Figure 3.5. Stratigraphic column of the Unit 1 and Crownpoint sites.

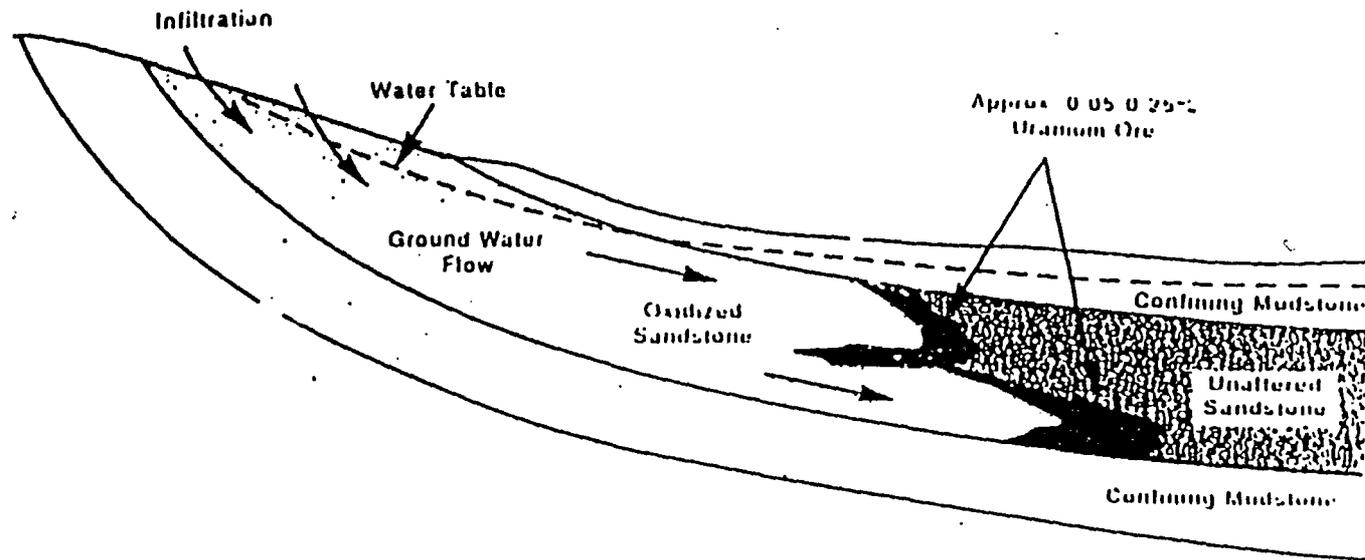


Figure 3.4. Simplified cross-section of roll-front uranium deposits formed by regional groundwater migration.

## Potential for Contaminant Excursions

- Monitoring to detect excursions long before mining solutions seriously degrade groundwater quality outside well field area.
- Horizontal excursions easy to detect/ control.
- Contamination due to vertical excursions takes much longer to detect/correct.
- **Vertical excursion into Dakota Sandstone or Cow Springs aquifers could contaminate Crownpoint water supply. Monitoring will be done in aquifers above and below mine zone; not in Cow Spring (poor producer; drilling enhances possibility of excursion).**
- NRC staff consider that **upper monitor wells may not detect excursion** if strong gradient.
- They therefore propose to rely on pre-mining **pump tests to confirm aquifer confinement.**
- They associate **vertical pathways** with thin or missing confining units; open faults, fractures, boreholes; broken casings; high injection pressures that fracture confining units; but **primarily with inadvertent leakage from installed wells.**

### Well Completion Method

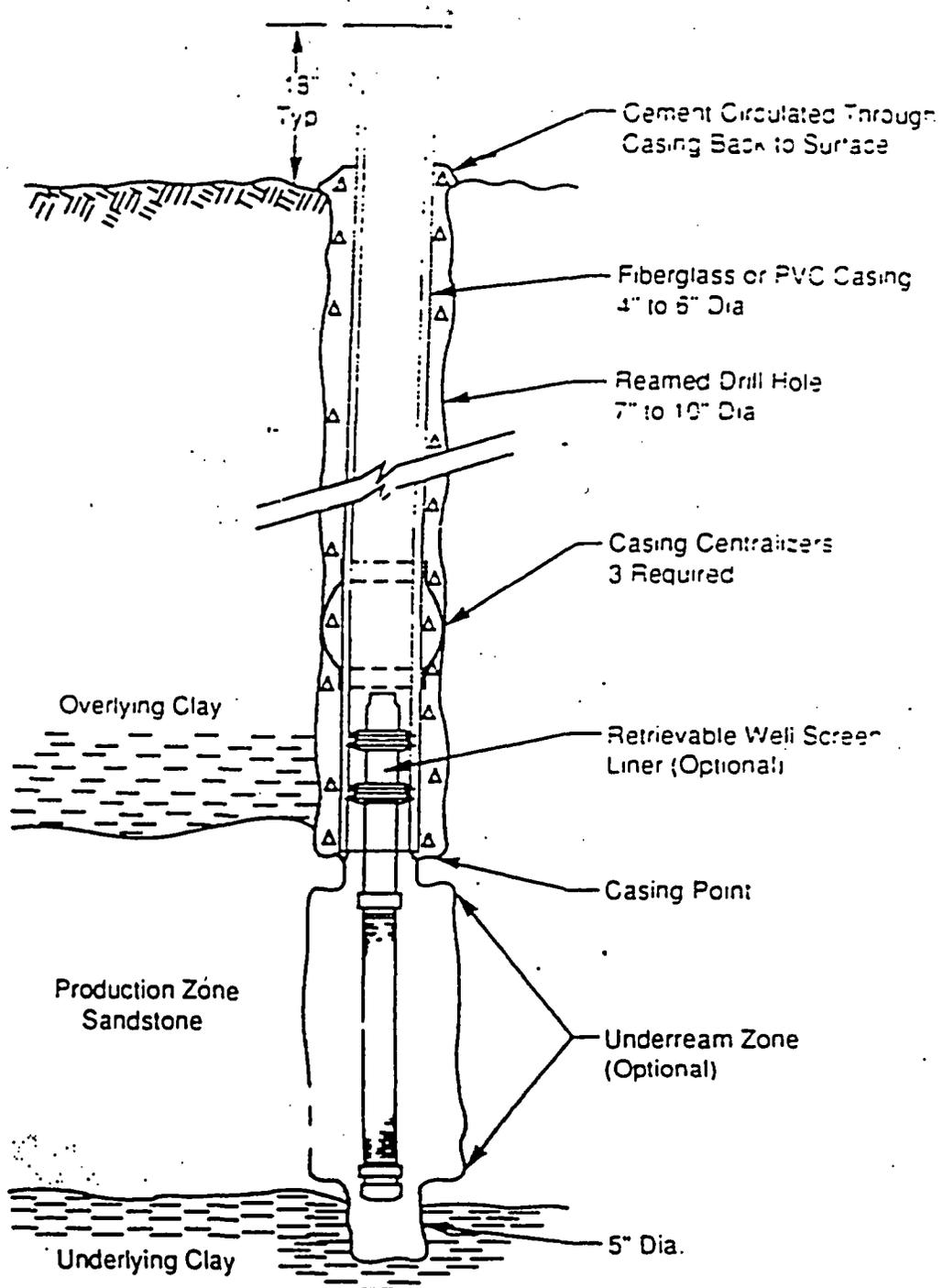


Figure 2.2. Cross-section of a typical injection, production, or monitor well completed using the underreamed method.

- Wells in Dakota are intervening Brushy Basin B sand aquifers did not respond to 3-day pumping tests of underlying Westwater Canyon: NRC staff concluded that Westwater Canyon is not hydraulically connected to either of the overlying aquifers in the area.
- Based on this, geology, borehole sealing and integrity testing programs, the staff considers the risk of vertical excursion to be low.

**Modeling** of ambient and operational flows in the Westwater Canyon was conducted by HRI. Though details are not given, it appears that the unit was considered to be hydraulically **uniform, isotropic and perfectly confined.**

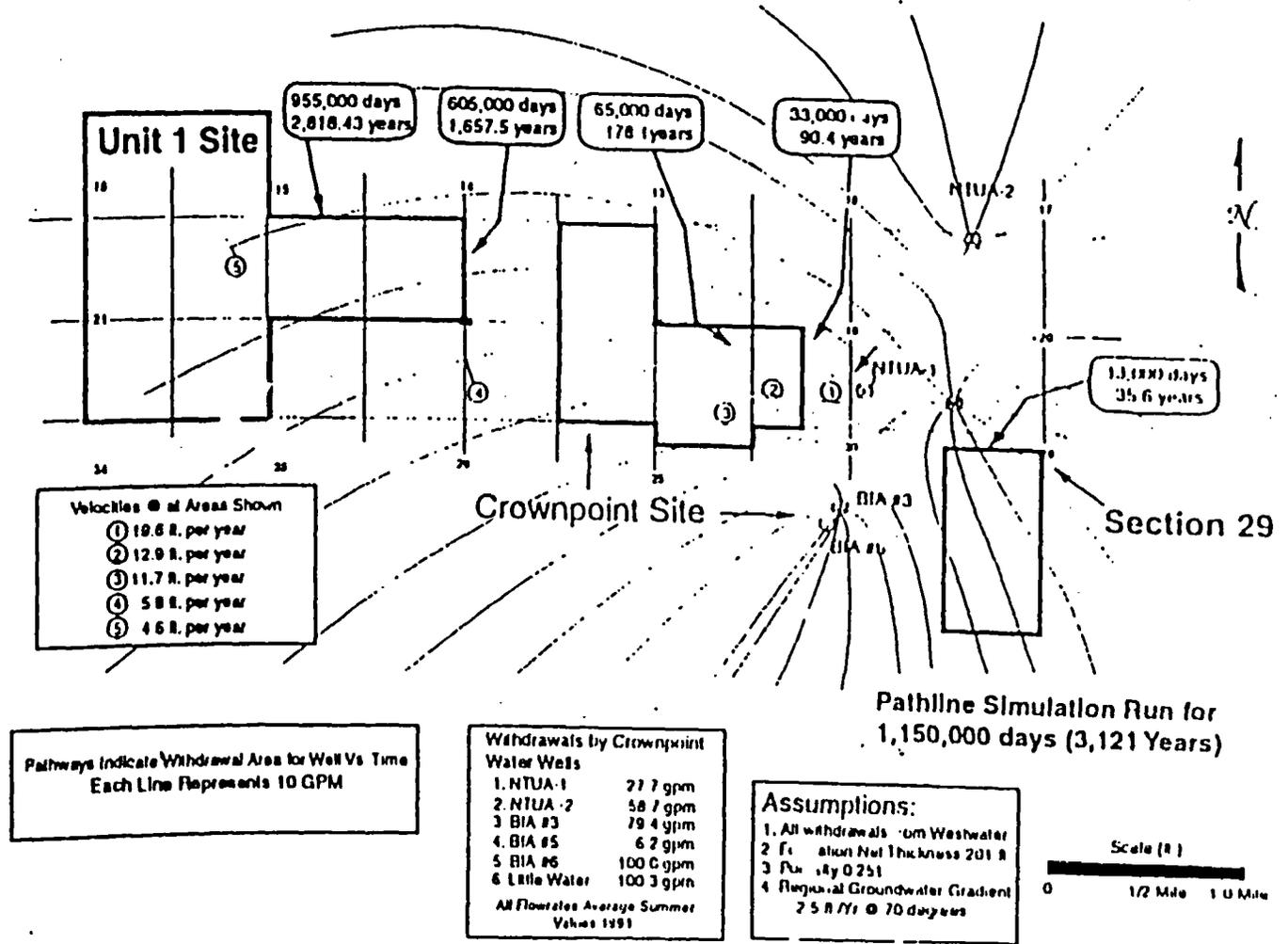


Figure 3.10. Modeled groundwater flow pathways for the Unit 1 and Crownpoint sites.

The above fails to consider

- The multiaquifer theory (*WRR* 5(4), 1969) and large-scale long-term field experiment (*WRR* 8(5), 1972) of Neuman and Witherspoon which demonstrate that
- During a standard pumping test, drawdowns in overlying/underlying aquifers take weeks or months to develop and are hard to detect due to ubiquitous background noise;
- Drawdowns in pumped aquifer, especially within/near pumping well, are often not sufficient to detect leakage or establish hydraulic properties of confining units;
- To do so unambiguously may necessitate installing monitoring wells in confining units and interpreting drawdowns using the ratio method of Neuman and Witherspoon.
- Injection at high pressures may cause major leakage without creating hydraulic fractures.

Hence hydrogeologic Conceptual Framework behind the FEIS is flawed (neither realistic nor conservative) and therefore indefensible.

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

In the Matter of  
HYDRO RESOURCES, INC.

Docket No.(s) 40-8968-ML

CERTIFICATE OF SERVICE

I hereby certify that copies of the foregoing MEMO HOLONICH TO COTTER have been served upon the following persons by U.S. mail, first class, except as otherwise noted and in accordance with the requirements of 10 CFR Sec. 2.712.

Office of Commission Appellate  
Adjudication  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555

Administrative Judge  
B. Paul Cotter, Jr.  
Presiding Officer  
Atomic Safety and Licensing Board Panel  
Mail Stop - T-3 F23  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555

Administrative Judge  
Thomas D. Murphy  
Special Assistant  
Atomic Safety and Licensing Board Panel  
Mail Stop - T-3 F23  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555

John T. Hull, Esq.  
Mitzi A. Young, Esq.  
Office of the General Counsel  
Mail Stop - 0-15 B18  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555

Diane Curran, Esq.  
Harmon, Curran, Spielberg & Eisenberg  
2001 S Street, N.W., Suite 430  
Washington, DC 20009

Susan G. Jordan, Esq.  
Douglas Meiklejohn, Esq.  
New Mexico Environmental Law Center  
1405 Luisa Street, Suite 5  
Santa Fe, NM 87505

Jep Hill, Esq.  
Attorney for Hydro Resources, Inc.  
Jep Hill & Associates  
P.O. Box 2254  
Austin, TX 78768

Mervyn Tilden  
Mary Lou Jones  
Zuni Mountain Coalition  
P.O. Box 39  
San Rafael, NM 87051

J 1  
Docket No.(s)40-8968-ML  
MEMO HOLONICH TO COTTER

Lila Bird  
Executive Director  
Water Information Network  
P.O. Box 4524  
Albuquerque, NM 87106

Wm. Paul Robinson  
Chris Shuey  
Southwest Research and Information  
Center  
P.O. Box 4524  
Albuquerque, NM 87106

John J. Indall, Esq.  
Joseph E. Manges, Esq.  
Comeau, Maldegen, Templeman  
& Indall, LLP  
P.O. Box 669  
Santa Fe, NM 87504

Bernadine Martin  
P.O. Box #370  
Crownpoint, NM 87313

Grace Sam  
Marilyn Sam  
P.O. Box 800  
Gallup, NM 87305

Dated at Rockville, Md. this  
4 day of March 1998

Lori Goodman  
Dine' CARE  
Navajo Nation  
10 A Town Plaza, S-138  
Durango, CO 81301

Mitchell Capitan, President  
ENDAUM  
P.O. Box 471  
Crownpoint, NM 87313

Anthony J. Thompson, Esq.  
Paul Gormley, Esq.  
Shaw, Pittman, Potts and Trowbridge  
2300 N Street, NW  
Washington, DC 20037

Mervyn Tilden  
P.O. Box 457  
Church Rock, NM 87311

*Adria T. Byrdson*  
Office of the Secretary of the Commission

# TEXAS WATER COMMISSION



Paul Hopkins, Chairman  
John O. Houchins, Commissioner  
B. J. Wynne, III, Commissioner

J. D. Head, General Counsel  
Michael E. Field, Chief Examiner  
Karen A. Phillips, Chief Clerk

Allen Beinke, Executive Director  
February 10, 1988

*Ty A  
Tr. J. / : : !*

Mr. Mark S. Pelizza  
Environmental Manager  
Uranium Resources, Inc.  
12377 Merit Drive  
Suite 750, LB14  
Dallas, Texas 75251

Re: Restoration Determination of Production Area No. 1 of the Benavides Mine Site, Permit No. URO2312-011

Dear Mr. Pelizza:

The Texas Water Commission has received the restoration data for Production Area No. 1 of the Benavides Mine Site. A review of the data indicates that Production Area No. 1 has been restored in accordance with the specifications contained in permit number URO2312-011 as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities, including monitoring, at Production Area No. 1.

Within 120 days of receipt of this letter closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans for this Production Area. Any modifications to the plugging and abandonment procedure must be approved in writing by the Commission.

Please notify the Commission prior to commencing plugging activities to provide the opportunity for TWC personnel to be present. If you have any questions please contact Dale P. Kohler of the In Situ Uranium Mining Unit at (512) 463-8278.

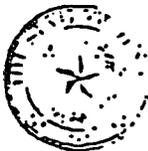
Sincerely,

*Harry D. Pruett*  
Harry D. Pruett  
Director, Water Rights & Uses Division

DK:jc  
cc TWC District 11 Office - Weslaco  
Mr. David Locker - Texas Department of Health  
Bureau of Radiation Control



# TEXAS WATER COMMISSION



B. J. Wynne, III, Chairman  
 John E. Birdwell, Commissioner  
 Cliff Johnson, Commissioner

John J. Vay, General Counsel  
 Michael E. Field, Chief Hearings Examiner  
 Gloria A. Vasquez, Chief Clerk

Allen Beinke, Executive Director

May 16, 1991

Mr. Mark Pelizza  
 URI, Inc.  
 12377 Merit Drive  
 Suite 750, LB14  
 Dallas, Texas 75251

*Ben  
TWC → URI*

Re: Restoration Determination of Production Area No. 2 of the Benavides Mine Site, Permit No. UR02312-021

Dear Mr. Pelizza:

The Texas Water Commission has received the restoration data for Production Area No. 2 of the Benavides Mine Site. A review of the data indicates that Production Area No. 2 has been restored in accordance with the specifications contained in permit number UR02312-021 as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities, including monitoring, at Production Area No. 2.

Within 120 days of receipt of this letter closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans for this Production Area. Any modifications to the plugging and abandonment procedures must be approved in writing by the Commission.

Please notify the Commission prior to commencing plugging activities to provide the opportunity for TWC personnel to be present. If you have any questions please contact Dale P. Kohler of the Ground Water Section at 512/371-6322.

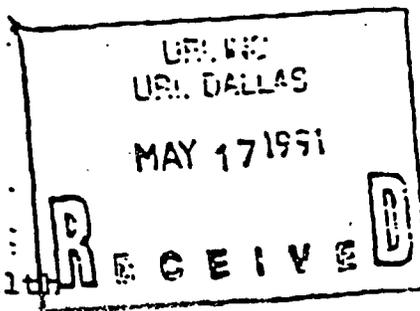
Sincerely,

*James Kewis for*

Harry D. Pruett, P.E.  
 Director, Water Rights & Uses Division

HDP/DPK/km

cc: TWC District Office #11 - Weslaco  
 David Lacker - Texas Department of Health  
 Bureau of Radiation Control



Attachment  
 C-3

# TEXAS WATER COMMISSION

J. Wynne, III, Chairman  
Paul Hopkins, Commissioner  
John D. Houchins, Commissioner



Allen Beinke, Executive Director  
Michael E. Field, General Counsel  
Brenda W. Foster, Chief Clerk

June 5, 1989

TWC 7 URI  
e

Mr. Mark S. Pelizza  
Environmental Manager  
Uranium Resources, Inc.  
12377 Merit Drive  
Suite 750, LB14  
Dallas, Texas 75251

Re: Restoration Determination of Production Area No. 3 of the Benavides Mine Site, Permit No. URO2312-031

Dear Mr. Pelizza:

The Texas Water Commission has received the restoration data for Production Area No. 3 of the Benavides Mine Site. A review of the data indicates that Production Area No. 3 has been restored in accordance with the specifications contained in permit number URO2312-031 as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities, including monitoring, at Production Area No. 3.

Within 120 days of receipt of this letter closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans for this Production Area. Any modifications to the plugging and abandonment procedure must be approved in writing by the Commission.

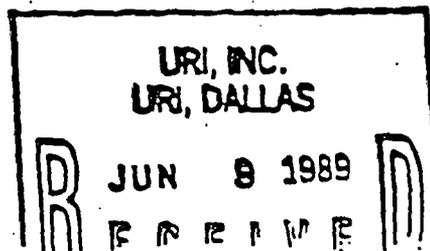
Please notify the Commission prior to commencing plugging activities to provide the opportunity for TWC personnel to be present. If you have any questions please contact Dale P. Kohler of the In Situ Uranium Mining Unit at (512) 463-8278.

Sincerely,

Harry D. Pruett  
Director, Water Rights & Uses Division

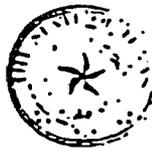
DPK:aa

cc: TWC District 11 Office - Weslaco  
Mr. David Lacker - Texas Department of Health  
Bureau of Radiation Control



# TEXAS WATER COMMISSION

Paul Hopkins, Chairman  
Ralph Roming, Commissioner  
John O. Houchins, Commissioner



Larry R. Soward, Executive Director  
Mary Ann Hefner, Chief Clerk  
James K. Rourke, Jr., General Counsel

October 31, 1986

Mr. Mark S. Pelizza  
Environmental Manager  
Uranium Resources, Inc.  
Suite 735, Promenade Bank Tower  
1600 Promenade Center  
Richardson, Texas 75080

**FILE**

*Bin  
CORR  
TWC 7081*

Re: Restoration determination, Uranium Resources, Inc., Benavides Mine Site, Permit No. UR02312-041, Duval County

Dear Mr. Pelizza:

The Texas Water Commission has received the three consecutive sampling sets as required by 31 TAC Section 331.107. A review of the restoration data indicates that Production Area No. 4 at the Benavides Mine Site has been restored in accordance with the specifications contained in permit number UR02312-041 and as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities including monitoring at this production area.

Within 120 days of receipt of this letter, closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans submitted as part of the permit application. Any modification to plugging and abandonment plans must be approved in writing by the Commission. Please notify the Commission prior to conducting plugging activities.

If you have any questions, please call Mr. Dale Kohler of the Commission's Ground Water Conservation Section at (512) 463-8278.

Sincerely,

Larry R. Soward  
Executive Director

cc: TWC District 11, Weslaco  
Mr. David Lacker, Chief, Bureau of Radiation Control,  
Texas Department of Health

# TEXAS WATER COMMISSION

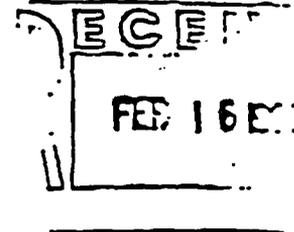


Paul Hopkins, Chairman  
 John O. Houchins, Commissioner  
 B. J. Wynne, III, Commissioner

Allen Beinke, Executive Director

February 11, 1988

J. D. Head, General Counsel  
 Michael E. Field, Chief Examiner  
 Karen A. Phillips, Chief Clerk



Mr. Mark S. Pelizza  
 Environmental Manager  
 Uranium Resources, Inc.  
 12377 Merit Drive  
 Suite 750, LB14  
 Dallas, Texas 75251

Re: Restoration Determination of Production Area No. 1 of the Longoria Mine Site,  
 Permit No. URO2222-011

Dear Mr. Pelizza:

The Texas Water Commission has received the restoration data for Production Area No. 1 of the Longoria Mine Site. A review of the data indicates that Production Area No. 1 has been restored in accordance with the specifications contained in permit number URO2222-011 as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities, including monitoring, at Production Area No. 1.

Within 120 days of receipt of this letter closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans for this Production Area. Any modifications to the plugging and abandonment procedure must be approved in writing by the Commission.

Please notify the Commission prior to commencing plugging activities to provide the opportunity for TWC personnel to be present. If you have any questions please contact Dale P. Kohler of the In Situ Uranium Mining Unit at (512) 463-8278.

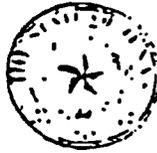
Sincerely,

Barry D. Pruett  
 Director, Water Rights & Uses Division

DK:jt

cc: TWC Dist 11 Office - Weisaco  
 Mr. David Lacker - Texas Department of Health  
 Bureau of Radiation Control

## TEXAS WATER COMMISSION



Paul Hopkins, Chairman  
John O. Houchins, Commissioner  
B. J. Wynne, III, Commissioner

J. D. Head, General Counsel  
Michael E. Field, Chief Examiner  
Karen A. Phillips, Chief Clerk

Allen Beinke, Executive Director

February 11, 1988

Mr. Mark S. Pelizza  
Environmental Manager  
Uranium Resources, Inc.  
12377 Merit Drive  
Suite 750, LB14  
Dallas, Texas 75251

Re: Restoration Determination of Production Area No. 2 of the Longoria Mine Site,  
Permit No. UR02222-021

Dear Mr. Pelizza:

The Texas Water Commission has received the restoration data for Production Area No. 2 of the Longoria Mine Site. A review of the data indicates that Production Area No. 2 has been restored in accordance with the specifications contained in permit number UR02222-021 as required by 31 TAC Section 331.107. You are hereby authorized to cease any restoration activities, including monitoring, at Production Area No. 2.

Within 120 days of receipt of this letter closure of the wellfield shall be accomplished in accordance with the approved plugging and abandonment plans for this Production Area. Any modifications to the plugging and abandonment procedure must be approved in writing by the Commission.

Please notify the Commission prior to commencing plugging activities to provide the opportunity for TWC personnel to be present. If you have any questions please contact Dale P. Kohler of the In Situ Uranium Mining Unit at (512) 463-8278.

Sincerely,

  
Harry D. Pruett

Director, Water Rights & Uses Division

DK:jt

cc: TWC Dist 11 Office - Weslaco  
Mr. David Lacker - Texas Department of Health  
Bureau of Radiation Control

TEXAS DEPARTMENT OF HEALTH  
AUSTIN TEXAS

INTER-OFFICE

**ATTACHMENT**

THRU: David K. Lacker, Chief  
Bureau of Radiation Control

THRU: *WJ* Edgar D. Bailey, C.H.P., P.E., Direc  
Division of Licensing, Registration,  
and Standards

FROM Joseph F. Thiel, Director  
Division of Environmental Programs TO License File #8-2704

SUBJECT: Recommended Radiological Restoration Values for Uranium Resources Inc.'s  
(URI) Benavides and Longoria Projects

Environmental Programs staff have reviewed the request from the TWC to specify radiological parameters to be included in amended restoration tables for URI's Benavides (PA No. 1) and Longoria (PA Nos. 1 and 2) projects. We make the following recommendations:

Uranium: 2mg/l.

Although the recommended value is above baseline average values for all three production areas, it is equal to or less than many uranium drinking water standards. Moreover, the average quality of the production zone water is considered only marginally suitable for drinking purposes (average TDS content ranges from about 1100 to 1900 mg/l).

Radium 226: Benavides No. 1, 83 pCi/l; Longoria No. 1, 97 pCi/l;  
Longoria No. 2, 37 pCi/l.

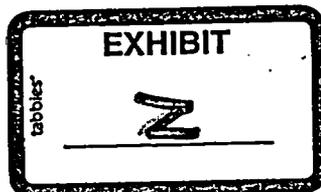
The recommended Ra-226 values are baseline levels.

Attachment

SDE/cal

cc: Board/JFT/SDE/CDR/Inspector's File (#8-2704)

*SDE*  
*ed*  
*5/04*



SIGNED *Joseph F. Thiel* Attachment  
DATE May 4, 1987 C-9

TEXAS DEPARTMENT OF HEALTH

AUSTIN

TEXAS

INTER-OFFICE

THRU: David K. Lacker, Chief  
Bureau of Radiation Control

THRU: Edgar D. Bailey, C.H.P., P.E., Direc  
Division of Licensing, Registration,  
and Standards

FROM Joseph F. Thiel, Director  
Division of Environmental Programs TO License File #8-2704

SUBJECT Modification to URI Longoria Restoration Table for Uranium to 3.0 mg/l

Division of Environmental Programs staff have reviewed the letter dated 5/12/87 from the Texas Water Commission (TWC), enclosing a request from URI for increasing the uranium value in the restoration table for the Longoria production area No. 1 aquifer to 3.0 mg/l. The earlier uranium value was 2.0 mg/l (see memo dated 5/4/87), which itself was a revision from the baseline value of 0.047 mg/l.

The new uranium value requested is more realistic in terms of achievability in comparison with TWC approved levels for other restoration parameters. No federal drinking water limits exist for uranium. Considering baseline water quality and pre-mining uses of water at the Longoria site, we feel that raising the uranium value as requested will not render the aquifer unsuitable for any purpose for which it was reasonably suited prior to mining.

Any questions should be referred to Stephen D. Etter.

CDR/cal  
cc: Board/CDR/SDE/JFT/Inspector's File (#8-2704)

529

SIGNED

*Joseph F. Thiel*

DATE

May 29, 1987

Attachmer  
C-10

TEXAS DEPARTMENT OF HEALTH

AUSTIN

TEXAS

2704

INTER-OFFICE

THRU: David K. Lacker, Chief  
Bureau of Radiation Control

Edgar D. Bailey, P.E., C.H.P., Director  
Division of Licensing, Registration,  
and Standards

ATTN: Warren D. Snell *WDS 3/27/86*

FROM Joseph F. Thiel, Director  
Division of Environmental Programs

SUBJECT Radiological Parameters for Amended Restoration Table: Uranium Resources, Inc.,  
Benavides Mine (Lic. # 8-2704)

Environmental Programs staff have reviewed the request from the Texas Water Commission to set radiological parameters for an amended restoration table for PAA Nos. 1 and 4 at Uranium Resources, Inc.'s (URI) Benavides in situ mine. The company requests limits of 83 pCi/l and 4 mg/l for RA-226 and uranium respectively. Staff concurs with 83 pCi/l for radium but recommends 2 mg/l for uranium.

We don't entirely understand the company's reasons for splitting old production area 1 into two parts, especially since no further production is contemplated. There are certainly some questions on the validity of applying the original baseline values to both new production areas. If the sole reason is to enable URI to claim they have indeed restored a wellfield, then we see little merit in it. However, we have no objection as long as the TWC concurs.

The radium value requested is the baseline value and we have no objection to using it.

The 4 mg/l requested for uranium, however, is much higher than baseline (.083 mg/l). Overall the water quality in the production aquifer is quite good. The baseline TDS content of 1211 mg/l indicates quality comparable to drinking water sources in other areas of the state. Similar requests for departures from baseline to 2 mg/l have been made by other in situ operators for production aquifers with much worse water quality. We have granted those requests because 2 mg/l has been cited as a common drinking water standard and because companies appear to have had no problems in achieving that level. We feel 2 mg/l is appropriate as well in this instance. If 2 mg/l uranium is not acceptable to URI, then we would request a report from the company specifying the number of pore volumes already pumped, the current average uranium level, and an explanation as to why a level of 2 mg/l could not be achieved.

SDE:lk

cc:Board, <sup>SDE TP</sup> SDE, TWD, JFT, Lic. No. 8-2704, Inspectors file  
*wcp*

SIGNED

*Joseph F. Thiel*  
3/25/86

Attachment

DATE

C-11

July 23, 2001

HRI CROWNPOINT URANIUM PROJECT  
Financial Assurance Plan for Churchrock Section 17  
Summary

Category	Project Total	Contingency/ Profit	Contingency/ Profit
		15%	25%
Groundwater Restoration	\$4,089,818	\$613,473	
Groundwater Stability Analysis	\$56,000	\$8,400	
Well Plugging	\$251,045	\$37,657	
Wellfield D & D	\$52,250		\$13,062
Surface Reclamation	\$7,153		\$1,788
<b>Totals</b>	<b>\$4,456,265</b>	<b>\$659,529</b>	<b>\$14,851</b>
<b>Contingency/Profit</b>			<b>\$674,380</b>
<b>Total Surety Proposed</b>			<b>\$5,130,645</b>



September 14, 2001

**HRI CROWNPOINT URANIUM PROJECT**  
**Restoration Action Plan for the Unit 1 Site**

**Cost Summary**

<b>Category</b>	<b>Project Total</b>	<b>Contingency/ Profit 15%</b>	<b>Contingency/ Profit 25%</b>
<b>Groundwater Restoration</b>	<b>\$8,542,567</b>	<b>\$1,281,385</b>	
<b>Groundwater Stability Analysis</b>	<b>\$216,240</b>	<b>\$32,436</b>	
<b>Well Plugging</b>	<b>\$1,191,726</b>	<b>\$178,759</b>	
<b>Equipment Removal</b>	<b>\$59,600</b>	<b>\$8,940</b>	
<b>Wellfield D &amp; D</b>	<b>\$187,758</b>		<b>\$46,940</b>
<b>Building D &amp; D</b>	<b>\$98,775</b>		<b>\$24,694</b>
<b>Surface Reclamation</b>	<b>\$185,920</b>		<b>\$46,480</b>
<b>Totals</b>	<b>\$10,482,586</b>	<b>\$1,501,520</b>	<b>\$118,113</b>
<b>Contingency/Profit</b>			<b>\$1,619,633</b>
<b>Total Surety</b>			<b>\$12,102,219</b>



November 19, 2001

**CROWNPOINT URANIUM PROJECT**  
**Financial Assurance Plan**

**Project Cost Summary**

<b>Category</b>	<b>Project Total</b>	<b>Contingency/ Profit</b>	<b>Totals</b>
<b>Churchrock Section 8</b>	<b>\$8,180,872</b>	<b>\$1,277,021</b>	<b>\$9,457,893</b>
<b>Churchrock Section 17</b>	<b>\$4,456,265</b>	<b>\$674,381</b>	<b>\$5,130,646</b>
<b>Unit 1</b>	<b>\$10,482,586</b>	<b>\$1,619,633</b>	<b>\$12,102,219</b>
<b>Crownpoint</b>	<b>\$14,188,373</b>	<b>\$2,205,568</b>	<b>\$16,393,941</b>
<b>Totals</b>	<b>\$37,308,096</b>	<b>\$5,720,472</b>	<b>\$43,084,699</b>



March 1, 2005

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judges:

E. Roy Hawkens, Presiding Officer  
Dr. Richard F. Cole, Special Assistant  
Dr. Robin Brett, Special Assistant

In the Matter of: )  
)  
)  
HYDRO RESOURCES, INC. )  
P.O. Box 777 )  
Crownpoint, New Mexico 87313 )

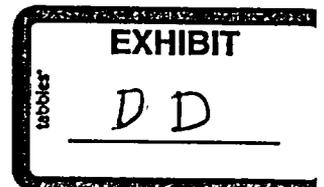
Docket No. 40-8968-ML  
ASLBP No. 95-706-01-ML

DECLARATION OF GARY R. KONWINSKI

I, Gary R. Konwinski, do hereby swear that the following is true to the best of my knowledge. I am qualified and competent to give this declaration, and the factual statements herein are true and correct to the best of my knowledge, information and belief. The opinions expressed herein are based on my best professional judgment.

Name and Qualifications

1. My name is Gary R. Konwinski. My mailing address is 5270 S. Zinnia Court, Littleton, Colorado, 80127. My education and experience as an earth scientist and regulatory professional in the areas of uranium recovery and nuclear materials are described in my résumé, which attached to this declaration as **Exhibit A**. I have bachelor of science and master of science degrees in earth sciences as well as additional graduate studies in geology and the physical



sciences. I have more than 30 years of experience in licensing and regulatory affairs associated with uranium recovery, nuclear decommissioning projects, and environmental effects of large projects. For 10 years, I was a Project Manager for the Nuclear Regulatory Commission's Uranium Recovery Field Office ("UFRO") in Denver, Colorado. In that capacity, I reviewed license applications for both conventional mills and *in situ* leach ("ISL") mines. I was the Project Manager for several Hydro Resources, Inc. ("HRI") projects and was one of the license application reviewers for the HRI Crownpoint Uranium Solution Mining Project between 1990 to 1993; consequently, I am familiar with the specific plans for ISL mining at Section 17, Unit I and Crownpoint. Through my work at UFRO, and more recently as Closure Project Manager at the Rocky Flats Environmental Technology Site near Denver, I became intimately familiar with estimating the costs of decommissioning of buildings and surface surfaces, conducting decontamination surveys, and disposing of waste materials at uranium- and plutonium-contaminated facilities. These experiences are directly applicable for evaluating HRI's financial surety cost estimates for the Crownpoint ISL mining and central processing site. Presently, I am an independent consultant, providing services for projects involving nuclear and environmental issues. I have regulatory experience, theoretical knowledge, and hands-on experience with nuclear licensing issues, regulatory documentation, and waste management.

#### Purpose of Declaration

2. I am giving this declaration on behalf of Eastern Navajo Diné Against Uranium Mining ("ENDAUM") and Southwest Research and Information Center ("SRIC") related to the licensing of Hydro Resources, Inc.'s ("HRI's") Crownpoint Uranium Project ("CUP"), located in Crownpoint and Church Rock, McKinley County, New Mexico. Specifically, I am testifying on issues related to financial assurance for decommissioning, decontamination, and closure of

HRI's proposed solution mine and processing plant at the proposed Crownpoint site. This is the first testimony I have given in this proceeding.

Licensing Materials and Literature Reviewed

3. In preparing this declaration, I reviewed HRI's Crownpoint Restoration Action Plan ("Crownpoint RAP") (November 19, 2001), the project's source and byproduct materials license (SUA-1508, January 5, 1998) (NB 11, ACN 980116066), the NRC Staff's Safety Evaluation Report (December 1997) (NB 10.4, ACN 9712310298), HRI's Consolidated Operations Plan, Revision 2.0 ("COP 2.0") (August 15, 1997) (NB 10.3, ACN 9708210179), the NRC's *Final Environmental Impact Statement* ("FEIS") for the HRI Crownpoint Uranium Project (NUREG-1508, February 1997) (NB 10, ACN 9703200270), HRI's response to NRC's Request for Additional Information ("RAI") #28 (NB 9, ACCN 9602220389), and relevant portions of HRI's application, including the Crownpoint Project Technical Report (June 12, 1992) (NB 5.1, ACN 9509080094). In addition to reviewing these documents, I had e-mail correspondence and personal conversations with representatives of the following companies, relative to disposal of 11e(2) byproduct materials: COGEMA Mining, Casper, Wyoming; ENVIROCARE of Utah, Inc.; and International Uranium Corporation ("IUC"), Blanding, Utah. I also reviewed and reference herein federal financial assurance regulations at 10 CFR Part 40, Appendix A, Criterion 9 (regarding financial assurance requirements for uranium recovery operations) and 49 CFR 173 (regarding nuclear waste classification associated with transportation on public highways), and NRC requirements for minimizing proliferation of small disposal sites at 10 CFR Part 40, Appendix A, Criterion 2.

### Summary of Expert Findings

4. Based on my experience, review of the referenced regulations, the content of HRI's Crownpoint RAP and the provisions in License Condition ("LC") 9.5 of SUA-1508, it is my professional opinion that (1) HRI does not have an assured legal disposal location for its 11e(2)<sup>1</sup> byproduct material, (2) options for disposal of 11e(2) material at licensed facilities in the region are limited, and (3) the surety amount estimated by HRI is not sufficient to support third-party decommissioning, decontamination, and closure of the proposed solution mining and processing operations at the Crownpoint site, in violation of 10 CFR 40 Appendix A, Criterion 9.

5. My first conclusion is based on the fact that HRI "assumed" that a certain facility in Utah would be the disposal location for its contaminated materials, but HRI provides no evidence that it has contracted with that facility to accept wastes from HRI's Crownpoint Uranium Project. Not having an assured location for off-site disposal of byproduct material, HRI risks having to dispose of these wastes at one or more of its CUP properties in contravention of Criterion 2 of 10 CFR 40 Appendix A.

6. As indicated by my second conclusion, the closest disposal facility to HRI's Crownpoint project limits the volume of wastes it receives from generators to a volume that may be less than that expected to be generated by HRI, especially if HRI is not successful in decontaminating *all* of its buildings and the concrete in them to meet unrestricted release criteria.

7. My third conclusion evolves from HRI's lack of consideration of the costs of disposing contaminated materials from dismantled buildings and the upper casings of injection and production wells at an off-site facility licensed to accept 11e(2) byproduct material. Additionally, HRI did not provide reasonable labor costs for radiological professionals to

conduct decommissioning and closure actions as well as costs for containerizing wastes packaged for off-site disposal at a licensed facility. These deficiencies amount to a failure by HRI to satisfy the requirements of Criterion 9 of 10 C.F.R. Part 40, Appendix A. Criterion 9 requires that "the licensee's cost estimates must take into account total costs that would be incurred if an independent contractor were hired to perform the decommissioning and reclamation work."

8. My objectives in assessing HRI's Crownpoint RAP were to (1) determine if NRC licensed-disposal capacity is available in the region for disposal of 11e(2) material, (2) compile cost estimates for disposal of such wastes at facilities licensed and capable of receiving such wastes, and (3) identify areas where HRI ignored or underestimated costs it will certainly incur in conducting restoration, decommissioning and decontamination of the Crownpoint mining and processing site.

**I. HRI Has No Assured Licensed Disposal Facility for its AEA 11e(2) Wastes**

9. HRI's Crownpoint RAP (§ E.5, n.31) states that "HRI assumed that the NRC licensed site would be the IUC White Mesa Mill near Blanding, Utah." The only obvious support for this statement is a copy of a "Byproduct Disposal Agreement" entered into between HRI's parent company, Uranium Resources, Inc., of Lewisville, Texas, and International Uranium Corporation of Denver, Colorado. See, Crownpoint RAP, Attachment E-5-3 beginning with the fourth page. However, this agreement, which was dated July 26, 2001, addresses disposal of wastes from URI's Kingsville Dome Mine, not from HRI's Crownpoint Uranium

---

<sup>1</sup> In this declaration, I use the terms "uranium mill tailings," "by product material" and "11e(2) wastes" or "11e(2) materials" synonymously; they mean and refer to the wastes generating by the processing of uranium for its source material content, including contaminated structures associated with that processing.

Project. No other documentation in the RAP addresses a contracted, or even likely, disposal facility.

10. In 1996, HRI told the NRC Staff that it “plans to dispose of all solid waste generated by the project that cannot meet criteria for release for unrestricted use . . . at a NRC-licensed or similar-agreement state-licensed disposal facility. Currently, URI to HRI, is contracted with Energy Fuels Nuclear to use their Blanding, Utah site.” HRI Response to RAI #28 (February 20, 1996). (Energy Fuels was the previous operator of the White Mesa Mill before it was acquired by IUC.) However, HRI did not attach a copy of the contract it referred to in its response to the Staff, and I am aware of no such document in the record.

11. Without an assured disposal site for its 11e(2) residues, HRI would have to consider on-site disposal at one or more of its CUP properties.<sup>2</sup> Such a circumstance would contravene the requirement of Criterion 2 of 10 CFR 40 Appendix A, which states:

“To avoid proliferation of small waste disposal sites and thereby reduce perpetual surveillance obligations, byproduct material from in situ extraction operations, such as residues from solution evaporation or contaminated control processes, and wastes from small remote above ground extraction operations must be disposed of at existing large mill tailings disposal sites. . .”

Criterion goes on to set forth conditions under which this obligation may not be required, such as “the costs and environmental impacts of transporting the wastes to a large disposal site.” To my knowledge, though, HRI has not evoked any such reason for seeking a waiver from the Criterion 2 requirement. Accordingly, HRI has not demonstrated that it has an assured off-site disposal facility nor a contingency plan for seeking a license amendment or other authorization to dispose of its 11e(2) material at one or more of the CUP mining and processing sites.

---

<sup>2</sup> The FEIS (at 2-14) for the project states that “on-site disposal of 11e(2) by-product material. . . will not be authorized as a licensed activity.”

**II. Off-Site Disposal Options for Byproduct Material Are Limited**

12. My review of 11e(2) disposal options identified three existing locations for disposal of the HRI waste: ENVIROCARE Inc.'s multi-waste disposal facility in northwestern Utah; the Shirley Basin Mill, operated by COGEMA Mining in Shirley Basin, Wyoming; and the White Mesa Mill, operated by IUC in Blanding, Utah.

13. With respect to ENVIROCARE, Inc., on September 14, 2004, I spoke by phone with Mr. Berton Pinkham, Client Service Manager for ENVIROCARE, who stated that the company will be closing the disposal cell that is licensed to receive 11e(2) byproduct material in 2005. He said this is due to the minimal demand for disposal of this type of waste and the need to utilize this disposal capacity for other wastes that ENVIROCARE is licensed to receive. Due to the pending closure of this disposal cell, Mr. Pinkham was unwilling to provide cost estimates for disposal of 11e(2) byproduct material.

14. With respect to COGEMA's Shirley Basin Mill, during the week of September 20th, I spoke by phone with COGEMA's Donna Wichers, who provided estimated disposal costs for different waste streams and for varying volumes of wastes. Those costs at this facility are shown in Table 1 below. The Shirley Basin Mill is an operational facility that can accept 11e(2) byproduct material from off-site facilities.

**Table 1. Materials, Disposal Costs and Volume Categories for the Shirley Basin Mill**

Material	Cost for Disposal		
	< 10,000 ft <sup>3</sup>	2 <sup>nd</sup> 10,000 ft <sup>3</sup>	20,000 ft <sup>3</sup> +
Piping, valves, and associated components	\$11.00/ ft <sup>3</sup>	\$10.00/ ft <sup>3</sup>	\$9.00/ft <sup>3</sup>
Sludge , resins, and other liquid/wet wastes	\$11.00/ ft <sup>3</sup>	\$10.00/ ft <sup>3</sup>	\$9.00/ft <sup>3</sup>
Material	Cost for Disposal		
	<100 yds <sup>3</sup>	100-400 yds <sup>3</sup>	400+ yds <sup>3</sup>
Soils and concrete with out rebar	\$300.00/yd <sup>3</sup>	\$90.00/yd <sup>3</sup>	\$80/yd <sup>3</sup>
Soils and concrete with rebar	\$400.00/yd <sup>3</sup>	\$270/yd <sup>3</sup>	\$243/yd <sup>3</sup>

15. With respect to IUC's White Mesa Mill, during the week of September 20, 2004, I spoke by phone with Mr. Harold Roberts, who confirmed that the facility is licensed to accept 11e(2) byproduct material for disposal. Estimated disposal costs at this facility are shown in the Table 2 below.

**Table 2. Materials, Disposal Costs and Volume Categories for the White Mesa Mill**

Material	Cost for Disposal		
	< 10,000 ft <sup>3</sup>	2 <sup>nd</sup> 10,000 ft <sup>3</sup>	20,000 ft <sup>3</sup> +
Sludge, resins, and other liquid/wet wastes	\$15.00/ ft <sup>3</sup>	\$15.00/ ft <sup>3</sup>	\$15.00/ft <sup>3</sup>
Material	Cost for Disposal		
	<100 yds <sup>3</sup>	100-400 yds <sup>3</sup>	400+ yds <sup>3</sup>
Soils and concrete	\$100.00 yd <sup>3</sup>	\$100.00/yd <sup>3</sup>	\$100.00/yd <sup>3</sup>
Sediments, plastic, and so on	\$125.00/yd <sup>3</sup>	\$125.00/yd <sup>3</sup>	\$125.00/yd <sup>3</sup>
Set Costs: \$45.00 per hour for unloading and \$150.00 for decontamination and vehicle survey			

16. COGEMA's Shirley Basin Mill is nearly 1,000 miles from Crownpoint, and based on my experience with off-site disposal of uranium processing wastes, I doubt that HRI would consider transporting its waste there when a closer option is available. The White Mesa Mill is about 200 miles from Crownpoint, and therefore would appear to be a more viable disposal location for some, but not all, of the 11e(2) byproduct material generated by HRI. As I indicated in ¶¶ 9-10 above, HRI has identified the White Mesa Mill as a possible disposal location, and bases its cost estimates in the Crownpoint RAP on the assumption that it will dispose of its byproduct material at the Blanding mill. See, Crownpoint RAP, § E.5 and n.31.

17. The White Mesa Mill has limitations, though. It is currently limited to accepting 500 cubic yards of solid materials. I calculate from the information in Attachment E-5-1 of the Crownpoint RAP that HRI will generate at least 242 cubic yards of contaminated process equipment, such as tanks, pipes, pumps, reverse osmosis units and brine concentrator. While this

volume is within IUC's limits, HRI assumes in the Crownpoint RAP that *none* of its buildings or the concrete floors in them will require disposal at an off-site, licensed facility.<sup>3</sup> Ibid., § E-7 and Attachment E-7-1. This is possible, but rather unlikely. It was my experience while a Project Manager at the Nuclear Regulatory Commission's Uranium Recovery Field Office that contaminated concrete from floors and sumps at uranium processing facilities were rarely decontaminated to meet unrestricted release radiation standards and therefore had to be manifested as 11e(2) material to a licensed disposal facility. Unless IUC were to obtain a license amendment to allow expansion of its capacity to receive off-site 11e(2) wastes, HRI might not be able to use the White Mesa Mill for disposal of all of its contaminated equipment and building debris that does not meet unrestricted release criteria.

### **III. HRI's Crownpoint RAP Underestimates the Cost of Decommissioning, Decommission and Restoration ("DDR") of the Crownpoint ISL Mine and Processing Facility.**

18. I believe that several elements of HRI's cost estimate are lowered than is reasonable, and therefore the overall estimate is too low to generate a surety sufficient to allow a third party contractor to carry out DDR as required by Criterion 9 of 10 CFR 40 Appendix A. In the paragraphs that follow, I outline these underestimated costs.

19. Assuming for the sake of argument that HRI could disposal of its solid wastes and sludges at the IUC mill, I believe that its costs for doing so are substantially underestimated. As shown in Table 2 above, IUC does not reduce its per unit disposal cost for increasingly higher volumes of wastes as does COGEMA. In my inquiry, IUC's quoted rate for soils, concrete,

---

<sup>3</sup> HRI assumed that "100% of the buildings would be released for unrestricted disposal after decommissioning. For concrete floors it was assumed that 100% of the [Church Rock] Satellite would meet release standards." Crownpoint RAP, § 7.2.

sediments, plastic and other solid waste was \$125 per cubic yard, or nearly three times higher than HRI accounted for in the RAP. In Attachment E-5-1, HRI bases its disposal costs on a rate of \$3.52 per cubic foot, which is equal to \$43.61 per cubic yard. Accordingly, HRI's process equipment disposal costs may be low by a factor of nearly three (i.e., 2.87), suggesting that its costs for transporting and disposal of contaminated equipment would exceed \$75,000, and its total costs for equipment removal and disposal would approach or exceed \$171,000 rather than the \$59,600 estimated in the RAP. See, Crownpoint RAP, Attachment E-5-1 at 1-2.

20. Even if the Byproduct Disposal Agreement provided in Attachment E-5-3 of the Crownpoint RAP were applied to HRI's Crownpoint Uranium Project, the cost of disposal of process equipment is still too low. Provision 10.A.(i) of that agreement sets the cost of disposing of 1 ton of "Byproduct Material" at \$75. Since 1 ton is equal to 1 cubic yard (see, Attachment E-5-2, page titled "Transportation and Disposal"), HRI's estimated cost of \$43.61 per cubic yard is almost half of that charged by IUC for Kingsville Dome wastes.<sup>4</sup>

21. As shown in Attachment E-2-1 of the Crownpoint RAP, HRI projects generating about 5.3 million gallons per month of reverse osmosis reject water and brine from the brine concentration. These fluid waste streams will generate radium-contaminated sludges that will be stored in on-site surface impoundments until final site closure. FEIS at 2-12. Assuming that HRI does not seek nor obtain a license amendment to allow on-site disposal of 11e(2) material, these wastes will have to be disposed off site at a licensed facility. Yet, I can find no indication

---

<sup>4</sup> In inspecting the Crownpoint RAP, I discovered that its cost estimates for process equipment removal and disposal (§ E-5) and cost estimates for building demolition and decommissioning (§ E-7) are identical to the same estimates contained in the Unit 1 RAP (HRI, September 14, 2001). This cannot be true since final uranium processing, including yellowcake drying and packaging, will be done at the Crownpoint site, not at the Unit 1 site, which will have a much smaller satellite plant. FEIS at 2-13. Equipment removal and building demolition costs cannot be equal because there will be more equipment, larger buildings and more on-site contamination at the Crownpoint site. This leads me to believe that HRI has underestimated its disposal costs for the Crownpoint site even more than I have estimated in this declaration.

in the groundwater restoration budget (Attachment E-2-1), the equipment removal and disposal budget (Attachment E-5-1), the wellfield decommissioning budget (Attachment E-6-1), or the building decommissioning budget (Attachment E-7-1) that the costs of sludge removal and disposal, including removal and off-site disposal of pond liners, were even estimated. The existing ponds at the Crownpoint site cover 14 acres (FEIS at 3-54), and each ISL mining site would have a 2-acre brine pond (FEIS at 4-6) for management of wastes from the brine concentrator. My experience is that the volume of these wastes, and therefore their disposal costs, will be substantial. Yet, HRI has failed to include any costs for disposal of sludges, resins, brines and pond liners in its Crownpoint RAP estimate.

22. The unloading costs and decontaminating/surveying costs associated with waste disposal and vehicle release at any disposal facility also are not included in the HRI calculations. These costs would be based on the number of vehicle visits. Current costs at IUC are \$45.00 per hour for unloading as well as \$150.00 for decontamination and vehicle survey. These costs need to be added to the HRI disposal cost estimate. Unloading is estimated to take 2 hours per truckload of waste, equaling a per vehicle visit cost of \$240.00. Assuming 50, 20-cubic yard truckloads of waste, an additional \$12,000 should be added to the waste disposal cost estimate.<sup>5</sup>

23. The HRI cost estimate does not contain appropriate hourly wages and per diem costs for radiological professionals to conduct closure surveys, classify the waste, and provide radiological transportation records. My experience at The Rocky Flats Environmental Technology Site from 1998 to 2002 was that appropriately trained radiological control technicians are routinely paid \$23.00 to \$25.00 per hour, plus living expenses of at least \$75.00 per day. The HRI labor estimate (Attachment E-2-2), which allocates a \$30,000 annual salary for

---

<sup>5</sup> It is not clear from the estimates in Attachments E-5-2 and E-5-3 if these costs were included in the budget for equipment removal and disposal. If they were, they are not labeled as such or otherwise apparent.

a single "Radiation Officer," needs to be revised to account for realistic labor rates and associated living expenses. Reasonable pay for a radiological professional is \$50,000 per year (based on a 40 hour week @ \$24.00/hour), plus \$26,000 for living expenses (based on \$75.00 per day). Based on a 18-month decommissioning duration, the Radiation Officer estimate should be increased by \$45,000 (from HRI's estimate of \$30,000 per year to the realistic hourly and living expenses that are discussed above).

24. The HRI cost estimate does not include any costs for containerizing the various forms of waste. The wastes will include soils, sediments, concrete, resins, process components, pipe, and other materials. These are not the types of waste that can be placed into a dump truck and hauled hundreds of miles on public highways. Containment of the contaminated waste is essential to assure that licensed materials are compliantly disposed and not allowed to "spill" outside of the areas that are licensed by the NRC. Consequently, containerization of all of the wastes will be necessary to support safe transportation of 11e(2) byproduct materials. The HRI estimate should be revised to include costs for the types of containers and number of containers as well as costs to load the containers. Estimated additional costs associated with waste containerization are shown in Table 3 following this discussion.

25. Surveying and decontamination costs associated with safe and compliant truck transportation of the 11e(2) byproduct materials are not included in the HRI estimate. Prior to release of the trucks from the HRI site, it is reasonable to require a contamination survey of the transportation vehicle to determine if the truck can compliantly leave the restricted area. Additionally, the waste manifest will need to be supported by radiological surveys and documentation to be carried in the cab of the truck. There are no costs for these surveys and

**Table 3. Additional and Underestimated Costs of Waste Disposal  
at HRI's Crownpoint Project**

<b>Well field and Satellite Surface Reclamation</b>			
<b>Materials/Equipment</b>	<b>Waste type</b>	<b>In HRI Estimate</b>	<b>Estimated Volume of Waste/Comments</b>
Evaporation pond sediments (6-inch depth) sq ft = 26797 cu ft for 2 ponds	Sediments/plastic & so on	Yes	Sediment volume is reasonable.
Containerize sludge	Sediments/plastic & so on	No	70 drums @ \$15.00/drum = \$1,050.00
Drawings show a third pond	Sediments/plastic & so on	No	13,398 cu ft = \$62,030.00
Liners, folded volume (each) 2700 cu ft	Sediments/plastic & so on	Yes	2,700 cu ft
Drawings show a third pond	Sediments/plastic & so on	No	1,350 cu ft = \$6,250.00
Contaminated soil plant/well filed 436 cu ft @ \$3.52/cu ft	Sediments/plastic & so on	Yes	Volume may be too small and cost is too low. Only surveys can determine actual volumes
Surface casing injection/production wells (based on number of wells shown in Attachment E-6-1) 7 cu ft x 295 production wells 7 cu ft x 285 recovery well	Sediments/plastic & so on	No No	2,065 cu ft <u>1,995 cu ft</u> 4,060 cu ft = \$18,796.00
<b>Additional costs associated with well field and Satellite surface reclamation = \$88,126.00</b>			
<b>Process Equipment Removal and Disposal</b>			
<b>Materials/Equipment</b>	<b>Waste type</b>	<b>In HRI Estimate</b>	<b>Estimated Volume of Waste/Comments</b>
Tanks 29, Vol. 1300 cu ft	Sediments/plastic & so on	Yes	1300 cu ft
Sand from sand filters and resin from IX columns Four, IX tanks @ 8 ft diameter x 8 ft. high Seven, IX tanks @ 10 ft diameter x 8 ft. high Six, Sand filters @ 10 ft diameter x 8 ft. high	Liquid wastes	No	402 cu ft x 8 = 3,216 cu ft 628 cu ft x 8 = 5,024 cu ft 628 cu ft x 8 = 5,024 cu ft 1,658 cu ft = \$24,870.00
Containerize materials	Liquid wastes	No	226 drums @ \$15.00/drum = \$3,390.00
PVC Pipe, 3000 ft. @ 3-inch diameter Volume 108 cu ft	Sediments/plastic & so on	Yes	108 cu ft
Pumps 29, 5 cu ft/pump = 145 cu ft	Sediments/plastic & so on	Yes	145 cu ft
RO equipment, 1000 cu ft	Sediments/plastic & so on	Yes	1000 cu ft
Brine concentrator 4000 cu ft	Sediments/plastic & so on	Yes	4000 cu ft
Filter Press 24 x 12 x 6 ft Yellowcake dryer	Sediments/plastic & so on	No	1,728 cu ft <u>1,500 cu ft</u> 3,288 cu ft = \$15,222.00
Floor grating and concrete associated with drains and sumps, adjacent to IX and Sand Filters 300 x 2 x 1.0 ft. = 600 cu ft	Soils and concrete	No	600 cu ft = \$2,777.00
<b>Additional costs associated with process equipment removal and disposal \$46,259.00</b>			

Crownpoint Wellfield Buildings and Equipment Removal and Disposal			
Materials/Equipment	Waste type	In HRI Estimate	Estimated Volume of Waste/Comments
Well field pipe , 259240 lin. Ft, avg. diameter 2-inches = 3,181 cu ft	Sediments/plastic & so on	Partially	Volume too low should be 5,650 cu ft <b>2,469 cu ft = \$11,430.00</b>
Tubing vol. Well depth – 600 ft 40 wells, 2-inch diameter tube	Sediments/plastic & so on	Partially	Well depth is closer to 2000 ft tubing, cable, and wiring. Additional waste is: <b>1,221 cu ft = \$5,652.00</b>
Buried trunk line 62,000 lin. Ft. 51,000 lin ft 10" HDPE 11,000 lin ft 14" HDPE chipped volume 19,494 cu ft disposal volume 29,241 cu ft	Sediments/plastic & so on	Yes	No way to verify the volumes. It appears to be reasonable
Well field house disposal costs	Sediments/plastic & so on and Soils and Concrete	No	Unlikely that all wellfield house/equipment will be released. Some costs should be shown here
Header house disposal costs	Sediments/plastic & so on and Soils and Concrete	No	Unlikely that all header houses house/equipment will be released. Some costs should be shown here
Wellfield soil disposal @ 1% contamination = 13141 cu ft	Soils and Concrete	Yes	A low and perhaps a reasonable estimate
<b>Additional costs associated with wellfield building removal and disposal \$17,082.00</b>			

Notes:

1. Well field and component estimates taken from: Hydro Resources, Inc Crownpoint Restoration Action Plan, dated November 19, 2001
2. Additional costs are shown in bold printing and summarized in blue writing.

associated waste-shipping documentation records in the HRI estimate. The HRI estimate should be revised to include the costs for transportation survey and documentation.

26. The HRI estimate contains no costs for disposal of the upper portions of the injection and recovery wells. The portions of the casings will have been in contact with the same well-field solutions as the process lines and should have the same waste management as the process lines. The interiors of the casings will contain byproduct materials (i.e., radium-contaminated scales) and will require disposal in an NRC licensed site. These portions of the well casings should be managed as 11e(2) material and treated with the same care as the process lines. The cost for removal, packaging, and disposal of these contaminated casings needs to be included in the cost estimate. Based on the upper portion of the casing that is removed to

support well abandonment, I estimate the individual well waste volume at 7 cubic feet. The HRI estimate should be revised to include contaminated-waste disposal for the portions of the injection and recovery wells that are removed.

27: I conclude that the HRI calculated costs for 11e(2) byproduct material disposal are underestimated and do not include costs (or provide insufficient cost estimates) for the line items listed above. The equipment removal and disposal costs contained in HRI's Crownpoint Restoration Action Plan need to be revised in accordance with License Condition Number 9.5 of Materials License SUA-1508. The current cost estimate is not sufficient to conduct compliant and safe closure of the operation if the work had to be performed by an independent contractor as required by 10 CFR 40, Appendix A, Criterion 9. Based on my review of the budgets contained in the RAP, I estimate that, at a minimum, an additional \$320,000 is necessary for third party decommissioning and decontamination of the project facilities, as summarized below:

- \$12,000 – Unloading, survey and decontamination costs @ the disposal site
- \$45,000 – Reasonable labor and lodging for Radiological expert
- \$88,126 – D&D of well field and satellite facilities
- \$111,400 – Underestimate of current costs of equipment removal and disposal
- \$46,259 – Process equipment removal and disposal
- \$17,082 – Crownpoint well field building contaminated equipment disposal

On top of these additional costs would be the costs of disposing of pond sludges and pond liners used to store restoration wastes. This category alone could exceed an estimated \$100,000.

28. This concludes my testimony.

Pursuant 28 U.S.C. §1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 1st day of March 2005



Gary R. Konwinski

# EXHIBIT A

**GARY R. KONWINSKI**

**5270 South Zinnia Court  
Littleton, Colorado  
80127**

**Phone: 303-979-7928  
Fax: 303-979-4901**

**SUMMARY**

Twenty-nine years of experience in applied sciences, including fifteen years of program development and project management. Comprehensive knowledge of operational, regulatory, licensing, compliance, remediation, decommissioning and decontamination issues associated with hazardous, radiological, and mixed-waste treatment storage and disposal facilities.

**ACCOMPLISHMENTS**

- Program Manager for closure projects associated with hazard reduction, decommissioning and demolition of nuclear facilities.
- Implemented regulatory programs at nuclear facilities, radioactive waste disposal sites, uranium mill tailings sites and mining sites as well as at nuclear fuel fabrication facilities.
- Established the Standard Review and Content Plan for alternate concentration limits for ground-water compliance at Title I and Title II UMTRCA sites.
- Functioned as the Contractors Technical Representative for numerous environmental restorations, decommissioning, waste management, engineering contracts.
- Served as regulatory consultant and expert witness for the nuclear industry and real estate developers.
- Established monitor well networks and determined plume characteristics for remediation technologies at waste disposal sites.
- Conducted building characterizations to determine the extent of radiological, asbestos, beryllium, and heavy metal contamination.
- Functioned as a Radiological Safety Inspector with the Nuclear Regulatory Commission.
- Operated a drill rig to determine the extent and engineering traits of rock and soil units for dam construction.
- Authored numerous Environmental Impact Statements, Proposed Action Memorandums, several Soil Survey Reports, portions of 10CFR, Part 40, and RCRA Permits.

**PROFESSIONAL EXPERIENCE**

**Environmental and Regulatory Consultant**

Gary R. Konwinski, LLC

07-02 to Present

- Independent consultant, supplying environmental and regulatory guidance to realtors, commercial property owners, mining companies, nuclear operations, and similar industries associated with distressed properties.

**Manager, Contaminated Equipment Removal**

01-02 to 07-02

Rocky Flats Closure Site Services, L.L.C., Golden, CO

- Manager of contaminated equipment removal from a 300,000 square foot nuclear facility formerly managing beryllium and depleted uranium. A ten million dollar project.
- Responsible for the safe and compliant implementation of work planning, waste management, decontamination, and building demolition.

**Departmental Manager - Work Control Center**

11-00 to 01-02

Rocky Flats Closure Site Services, L.L.C., Golden, CO

- Engineering Program Manager for all work planning, scheduling, and implementation of maintenance activities in nuclear, industrial, and office facilities. A nine million dollar project.
- Subcontract Administrator for engineering, planning, and work reception services.

**Closure Project Manager**

03/00 to 11-00

Rocky Flats Closure Site Services, L.L.C., Golden, CO

- Closure Project Manager responsible for efficiently decontaminating and decommissioning former nuclear facilities. A six million dollar project.
- Manager of nuclear and RCRA waste removal from classified research and development facilities in the DOE complex.

**Project Manager**

05/98 to 03/00

Rocky Mountain Remediation Services, L.L.C., Golden, CO

- Project Manager responsible for orderly shut down of former beryllium and depleted uranium processing facilities at Rocky Flats Environmental Technology Site.
- Responsible for a 4.4 million dollar budget supporting building management, hazard reduction, environmental compliance, waste management, and facility characterization.

**Environmental Manager**

07/95 to 05/98

Rocky Mountain Remediation Services, L.L.C., Golden, CO

- Manager of all environmental compliance activities, including the waste chemical, self-assessment, used oil, RCRA, nuclear metal and TSCA programs.
- Work Package Manager responsible for a 6.0 million-dollar environmental compliance program including all RCRA permitting and waste management activities.
- Technical compliance oversight individual for Waste Management, Environmental Restoration, and Decommissioning organizations.
- Designated Environmental Manager for the Hazard Assessment Center at the Rocky Flats Plant Emergency Operations Center.

**Manager, Geoscience Division**

01/94 to 07/95

EG&amp;G Rocky Flats Inc., Golden, CO

- Responsible for an 8.9 million-dollar budget directed at characterization of hazardous and nuclear waste disposal sites.
- Supervisor of engineers and scientists involved in remediation technology development.
- Program Manager tasked with implementing Waste Minimization and Pollution Prevention programs at Department of Energy facilities.

**Radiological Safety Inspector/Hydrogeologist**

09/83 to 01/94

Nuclear Regulatory Commission, Denver, CO

- Radiological safety enforcement official responsible for all aspects of uranium recovery, nuclear material processing, and waste disposal activities.
- Program Manager responsible for the development of ground-water remediation actions, gaseous attenuation measurements, and long-term stabilization at uranium mills.
- Technical reviewer of licensee applications for waste disposal sites, uranium recovery facilities, and remediation proposals.
- Interdisciplinary liaison between the Environmental Protection Agency, the Department of Energy, the Nuclear Regulatory Commission, Indian Nations, State governments, and the general public assuring consistent regulation at Superfund sites and nuclear facilities throughout the United States.

**Team Leader/Geologist**

01/80 to 09/83

Bureau of Land Management, Denver, CO

- Team Leader managing a group of technical specialists in the preparation of Environmental Impact Statements for large energy related projects on public lands.
- Agency representative chosen to coordinate Department of Interior functions with the Air Force on deployment of the MX Missile System.

- Field geologist collecting data on site stability, mineral resources, and alternative energy sources.

**Geologist**

08/77 to 01/80

Soil Conservation Service, E. Lansing, MI

- Field geologist conducting earthen structure foundation investigations.
- Installed, maintained, and sampled ground water wells and surface water monitoring stations.
- Conducted sediment and pesticide accumulation research in flood storage reservoirs.

**Soil Scientist**

09/74 to 08/77

Soil Conservation Service, Grand Rapids & Kalamazoo, MI

- Field soil scientist tasked with landform analysis and producing Soil Survey Reports.
- Produced and compiled an aerial photo base map for Southern Michigan.
- Developed technical guides on the engineering uses of glacial deposits.

*EDUCATION*

**Post-Graduate Studies in Geology and Engineering**

1981 to 1983

Colorado School of Mines, Golden, CO

**Post-Graduate Studies in Applied Sciences**

1977 to 1979

Michigan State University, East Lansing, MI

**MS in Geological Earth Sciences**

1976 to 1978

Western Michigan University, Kalamazoo, MI

**BS in Earth Sciences**

1969 to 1974

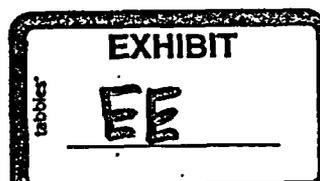
University of Wisconsin, Madison, WI

## Building and Demolition and Disposal

### Assumptions:

Crownpoint offices will be left intact after the project ends

	<u>Description</u>	<u>Satellite</u>	<u>Cost</u>
I.	<b>Decontamination Costs</b>		
A.	Wall decontamination		
	Area to be decontaminated (ft <sup>2</sup> )	12167	
	Application rate (gallons/ft)	1	
	HCl acid wash, including labor (\$/gallon)	\$0.50	
	Subtotal wall decontamination costs	\$6,083	\$6,083
B.	Concrete floor decontamination		
	Area to be decontaminated (ft <sup>2</sup> )	10491	
	Application rate (gallons/ft)	4	
	HCl acid wash, including labor (\$/gallon)	\$0.50	
	Subtotal concrete floor decontamination costs	\$20,982	\$20,982
II.	<b>Demolition Costs</b>		
A.	Building		
	Dryer bldg. demolition unit cost of \$0.75/ft <sup>3</sup> for additional radiation safety precautions.		
	Volume of building (ft <sup>3</sup> )	209820	
	Demolition unit cost per WDEQ Guideline No. 12 (\$/ft <sup>3</sup> )	\$0.15	
	Dryer building demolition unit cost (\$/ft <sup>3</sup> )		
	Subtotal building demolition costs	\$31,893	\$31,893
B.	Concrete floor		
	Area of concrete floor (ft <sup>2</sup> )	10491	
	Demolition unit cost (ft <sup>3</sup> ) per local estimate	\$1.20	
	Subtotal concrete floor demolition costs	\$12,589	\$12,589
III.	<b>Disposal Costs</b>		
A.	Building		
	Volume of building (cy)	7771	
	1 Unrestricted		
	Unrestricted disposal cost of 26.7 \$/yd <sup>3</sup>	\$27.00	
	Building will collapse to 10% of standing volume	.777	
	Percentage (%) on site	100	
	Subtotal unrestricted disposal costs	\$20,982	\$20,982
B.	Concrete floor		
	Area of concrete floor (ft <sup>2</sup> )	10491	
	Average Thickness of concrete floor (ft)	0.5	
	Volume of concrete floor (ft <sup>3</sup> )	5246	
	Volume of concrete floor (cy)	194	
	1 Unrestricted		
	Percentage (%)	100	
	Volume for disposal (ft <sup>3</sup> )	194	
	Disposal unit cost \$/cy	\$27.00	
	Subtotal on-site disposal costs	\$5,246	\$5,246
III.	<b>Health and Safety Costs</b>		
	Total health and safety costs		\$1,000
	<b>TOTAL BUILDING DEMOLITION AND DISPOSAL COSTS</b>		<b>\$98,775</b>



ANALYSIS OF HYDRODYNAMIC CONTROL  
HRI, INC.  
CROWNPOINT AND CHURCHROCK, NEW MEXICO URANIUM MINES

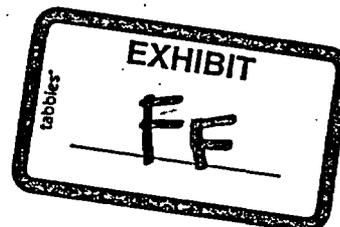
BACKGROUND

In-situ methods of mining have been used since the mid-seventies to extract uranium from ore. The in-situ methodology was developed because it:

- Requires less surface disturbance than open-pit mining methodology;
- Allows groundwater consumption to be minimized;
- Can be cost-effective for both shallow and deep ore bodies.

Uranium that resides in ore bodies is in a chemical state that makes it insoluble in water. In fact, it is this insolubility that promoted the deposition of the uranium within the ore body. In-situ methods of uranium extraction simply involve changing the uranium from its insoluble form to a soluble form that can be extracted through wells. Using a network of injection wells, fluids are injected into the ore body to oxidize the uranium, thereby placing it into solution. The solubilized uranium is then produced through extraction wells.

Most of the uranium ore bodies in the United States that are amenable to in-situ leaching are contained within groundwater systems that, at least on a regional basis, yield groundwater that can be used either for human consumption or agriculture. It is, therefore, necessary that fluids circulated through the ore be contained within the immediate area of the mine. Two types of containment are necessary. It is important to control the vertical migration of mining fluids so that the quality of groundwater in the aquifers overlying and underlying the mine zone not be adversely effected. Secondly, horizontal control of mining fluids is important to prohibit the horizontal dispersion of mining fluids that might affect the users of the aquifer beyond the mine area.



Uranium ore is commonly contained within clastic deposits, usually within sands near their basal contact with low permeability sediments such as clays or shales. Ore bodies considered ideal for in-situ mining are those that are both underlain and overlain by clays or shales. These low permeability units provide the vertical containment of mining fluids, such that the fluids do not escape into either underlying or overlying aquifers. Horizontal containment is provided by hydrodynamic control.

### PURPOSE

Geraghty & Miller was retained to evaluate the HRI Churchrock and Crownpoint Mines to determine if horizontal and vertical control of mining fluids was possible using the in-situ methodology. This evaluation consisted of two parts. First, the geology of the ore body and units above and below the mine zones were evaluated to determine if vertical control would be established. This evaluation included a determination as to whether the ore body sand is continuous across the mine area, a determination of the competence of overlying and underlying zones to contain the fluids, and a determination if there are natural conduits such as geologic faults that could effect vertical containment. The second aspect of this evaluation was a determination of the ability to impose hydrodynamic control on the ore body groundwater system. This report summarizes our findings on the ability to contain fluids to the mine zone in both the Crownpoint and Churchrock Mines.

### HRI CROWNPOINT MINE

#### LITHOLOGY

The uranium ore in the proposed HRI Crownpoint Mine is contained within massive sands of the Westwater Canyon Member of the Morrison Formation (Figure 1). These sands are continuous across the site of the mine, which is important because it allows HRI to control and monitor horizontal migration of mining fluids. The overall thickness of the sands containing the ore is approximately 200 feet.

The mining horizon is underlain by shales of the Recapture Member of the Morrison Formation. The Recapture shales are approximately 250 feet thick within the area of the Crownpoint Mine. The ore sands are overlain by the Brushy Basin Member of the Morrison Formation, which is comprised of shales approximately 70 feet thick in the mine area.

## STRUCTURE

Structural cross sections prepared by HRI were examined in detail for the evidence of geologic faults which could be conduits for migration of fluids out of the mine zone or which could reduce the effectiveness of the monitoring program. There is no indication that faults with any significant displacement are present within the mine area. A nearby seven-meter fault mapped by the U.S. Geological Survey (Crownpoint Quadrangle) is not evident in the mine area and, if present, is projected to cut the ore zone north of the mine.

## MINING FLUID CONTAINMENT

### Vertical Containment

Prior to filing the application for a discharge permit, HRI conducted a pumping test in the production zone to determine the effectiveness of the overlying Brushy Basin to contain fluids within the ore body. The pumping test consisted of producing groundwater from the mine zone while monitoring fluid levels in observation wells completed within the ore body, as well as within the first overlying aquifer above the Brushy Basin Member (Dakota Formation). An observation well completed in the production zone approximately 1930 feet from the pumping well experienced fluid level declines of approximately 14 feet during the test. However, an observation well completed in the Dakota Sandstone, approximately 1866 feet from the pumping well, showed no response to pumping. The lack of response in the first overlying aquifer indicates that the Brushy Basin shales provide adequate upper confinement for mining fluids. The thick Recapture shales will provide lower containment.

## Horizontal Containment

Data from the pumping test was also used to evaluate the hydraulic characteristics of the mine zone. To determine if mining fluids are contained within the mine area, an in-situ mine is monitored for horizontal hydrodynamic control through ore-zone depth monitor wells completed along the periphery of the ore body. The intent of the operation of an in-situ mine is to contain the mining fluids within this monitor well "ring."

Primary containment is through over-production relative to injection, referred to in the industry as a "bleed." Depending on the permeability of the aquifer, hydrodynamic control can generally be maintained with a bleed ranging from 0.5 to 2 percent.

HRI supplied to Geraghty & Miller its proposed configuration of injection and extraction wells (Figure 2) along with the proposed injection and extraction rates. This pattern of injection and extraction contemplated an overall bleed during mining of 1 percent, and a maximum 12.5 percent bleed during the final restoration phase. Geraghty & Miller modeled four well fields and the restoration process to determine the ability of HRI to control horizontal excursions.

(b) *Assumptions in model?*  
 The model used to evaluate both the Crownpoint and the Churchrock Mines is a Geraghty & Miller computer program that allows the modeler to turn injection and production wells on and off at various times using various rates. This model, called AQUASIM, utilizes the Theis non-equilibrium equations. The computer merely allows hundreds to thousands of computations to be made quickly that would otherwise take an inordinate amount of time to do by hand. Resulting computations yield an output file consisting of drawdowns calculated at regular grid intervals throughout the mine area. These drawdowns are then mathematically compared with the pre-mining hydraulic gradient to determine the predicted piezometric surface at any given time throughout the mining or restoration phases of the project.

*Yes!*

The first part of the modeling operation involves inputting or calculating a pre-mining hydraulic gradient. The second portion of the model involves inputting extraction and injection wells for both mining and restoration phases to determine the predicted aquifer response.

HRI has measured water levels at the Crownpoint Mine for the last several years, allowing Geraghty & Miller to create a hydraulic gradient map. The hydraulic gradient is directly affected by pumpage of nearby municipal wells. These wells, which are east of the mine area, create a steeper hydraulic gradient in the summer during peak production, and a less-steep, winter-time gradient. These gradients, simulated in AQUISIM and calibrated to actual data (including pumping rates of all the nearby municipal wells) are presented in Figures 3 and 4. Groundwater velocities calculated for the winter and summer gradients are 5.6 feet/year and 10.6 feet/year, respectively.

Once the hydraulic gradients were established, the mining schedule supplied by HRI was input to the model. Geraghty & Miller utilized the summer hydraulic gradient in the model because it represents the steeper of the two gradients.

Initial well field configurations supplied by HRI provided virtual hydraulic containment as predicted by the model, but small areas within the mine were predicted to have potential excursions sometime during the mining or restoration phases. Minor adjustments to the original proposed well schedule were made by HRI, and the final model simulations were prepared. These simulations are shown in Figures 5 through 10.

Computer simulated output maps were generated to show the piezometric surface at the end of each mining phase, as well as the end of the restoration of the final mining area. These points in time were used because they represent the points of maximum hydraulic stress on the aquifer during the mining and restoration phases.

There are two things that one looks for in these simulations. First, one looks to see that overall the bleed has created a groundwater "sink" on the periphery of the mine area, which promotes inward migration of groundwater toward the mine. Secondly, one looks for areas within the monitor well ring, particularly downgradient of the mining area, where groundwater is predicted to flow beyond the immediate area of the mine. In those portions of the mine that show continued downgradient migration of fluids, the length of the flow path is calculated for the point in time at the end of the particular mining cycle. As an example, Figure 5 shows that during mining of Area 1 there is an apparent flow path to the east-southeast. However, this flow path is toward the yet-to-be-mined portion of the ore body. The length of the flow path calculated at the end of the mine Area 1 production, however, shows that mining fluids will be well within the monitor well ring. Thus, no excursion is predicted.

In order to simulate variabilities in winter and summer hydraulic gradients and the ranges of transmissivities and storage coefficients measured during the pumping test, sensitivity simulations were made using the winter gradient and the measured high and low transmissivities and storage coefficients. These simulations, shown in Figures 10 through 12 indicate that there is no change in the ability to contain fluids using these variables. The simulations performed for the Crownpoint mining and restoration schedules indicate that, with a 1 percent bleed during mining and a 12.5 percent bleed during final restoration, the mining fluids can be adequately contained within the monitor well ring.

## REGIONAL RESERVOIR IMPACT

The computer simulations included a determination of the drawdown in water levels that would be experienced during critical stages of mining and restoration. These simulations (Figures 13 through 17) indicate that the maximum drawdown to be experienced at the nearest municipal well (NTUA No. 1) is 16 feet. The range in drawdowns at this well

## Response

The groundwater model used to predict the potentiometric surface changes due to mining at the Crownpoint mine is an analytical flow model developed by G&M to simulate aquifer response to pumping and/or inspection. The model uses the an approximation of the Theis equations for nonsteady state flow. A summary of the model with verification has been included as Attachment 77-1. Responses to the numbered subsections of Comment No. 77 are given below.

1. The pumping effects of the Crownpoint municipal water wells were evaluated and long term average flow rates estimated for the wells. In the model runs the average flow from the supply wells were 372 gpm.
2. The static potentiometric surface map presented in the G&M report was developed from several calibration model runs. This map was a representation of the measured static water levels in the Crownpoint monitor wells measured in August 1992, and the approximate average pumping rates for the six Crownpoint municipal water wells (NTUA-1, NTUA-C, NTUA-LW, BIA-3, BIA-5, and BIA-6). The model output was gridded with a widely used contouring program (Surfer) to provide a pre-mining potentiometric surface for the Westwater aquifer. The model runs were then made using the planned extraction and injection wells at the planned flow rates for the projected time periods. The output maps show only the Crownpoint well (NTUA-1) nearest to the mining wells so the detail of the potentiometric surface in the mine area could be seen. The pumping rates of all the Crownpoint water wells were, however, included in the model runs.
3. As described above, the model is an analytical flow model that utilizes the basic Theis equations for calculating the response to hydraulic stress at a defined distance from the well. The model uses the basic assumptions of the Theis equation.
4. As the described in Attachment 77-1, the model uses the Theis assumptions and the aquifer is considered to be an infinite aquifer with uniform transmissivity and storativity. No boundary conditions are assumed. The summary documentation is given in Attachment 77-1.
5. The aquifer parameters used in the model are shown on each model simulation map. The average transmissivity and storativity used were 2,550 gpd/ft and 0.000086, respectively. Sensitivity runs were made with a high transmissivity of 2,686 gpd/ft and a low transmissivity of 2,409 gpd/ft. While not needed in the analytical model for a confined unit, an average thickness and porosity of 200 feet and 0.25, respectively were used for the average groundwater velocity calculations.
6. The individual well pumping and injection rates were developed by URI based on pumping tests and experience. The well rates input to the model variable flow rates generally ranging from 20 to 40 gallons per minute. Because the individual rates are projected based on a field balancing program and when the wells are completed the actual rates will vary, the voluminous files were not believed to be necessary to present in the application.
7. The simulation periods were set up according to the preliminary mining plan for the Crownpoint area. This plan/schedule provides for four sequential production periods corresponding to four wellfields or blocks of wells. Simulations generally were set for the last day of mining from each of the four wellfields and the last day scheduled for restoration from the last wellfield.



the Churchrock Mine. The initial hydraulic gradient (Figure 20) was calibrated to actual data measured on observation wells for the last several years. The hydraulic gradient which yields a groundwater velocity of 8.7 feet/year, is not effected seasonally by pumpage, as is the case in the Crownpoint area. The primary impact of the regional hydraulic gradient is the cessation of dewatering for underground mining. Although the water levels continue to rise in response to cessation of pumping, the hydraulic gradient is not expected to change appreciably throughout the mining phase (see Figure 21).

W by  
ST

HRI's proposed mining plan includes operation of five mine areas. Simulations shown in Figures 22 through 27 indicate that, as with the Crownpoint Mine, hydraulic control can be readily established with a bleed of one percent during mining. Again, during those portions of the mining phases where complete reversal of the downgradient piezometric surface is not accomplished, the flow path lengths indicate that the mining fluids will be contained well within the monitor well ring at the end of each phase of mining and restoration (see, for example, Figure 22).

As with the Crownpoint simulations, sensitivity runs were made for variations in area transmissivities and storage coefficients. These simulations, shown in Figures 28 through 29, indicate that there is no appreciable difference in the ability to contain mining fluids using these ranges of aquifer parameters.

**REGIONAL RESERVOIR IMPACT**

Predicted drawdowns in the aquifer at the end of the mining phases and final restoration phase are shown in Figures 30 through 35. These calculations show that the decline in hydraulic head at the most downgradient monitor well (MW-20) will range from approximately 12 to 34 feet during the mining and restoration phases of this project.

12-34  
+ 2



February 25, 2005

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judges:

E. Roy Hawkens, Presiding Officer  
Dr. Richard F. Cole, Special Assistant  
Dr. Robin Brett, Special Assistant

\_\_\_\_\_  
In the Matter of: )  
 )  
HYDRO RESOURCES, INC. )  
P.O. Box 777 )  
Crownpoint, New Mexico 87313 )  
\_\_\_\_\_ )

Docket No. 40-8968-ML  
ASLBP No. 95-706-01-ML

DECLARATION OF DR. SPENCER G. LUCAS

I, Spencer G. Lucas, do hereby swear that the following is true to the best of my knowledge. I am qualified and competent to give this declaration, and the factual statements herein are true and correct to the best of my knowledge, information and belief. The opinions expressed herein are based on my best professional judgment.

Name and Title

1. My name is Spencer George Lucas. I am Curator of Paleontology and Geology at the New Mexico Museum of Natural History and Science in Albuquerque, New Mexico. My mailing address is 9408 Shoshone NE, Albuquerque, N.M., 87111.



### Purpose of Declaration

2. I am giving this declaration on behalf of Eastern Navajo Diné Against Uranium Mining ("ENDAUM") and Southwest Research and Information Center ("SRIC") related to the licensing of Hydro Resources, Inc.'s ("HRI's") Crownpoint Uranium Project ("CUP"). In particular, I am giving this declaration on the geology of the Jurassic-age sedimentary rocks that occur in the Church Rock and Crownpoint areas New Mexico to demonstrate that the rock layer that underlies the Westwater Canyon Member at Section 17 does not have the geologic properties of a confining layer, that the presence of a confining layer made of small-grained particles characteristic of a "true shale" is absent at the Unit I site west of Crownpoint, and that the Westwater Canyon Member is lithologically and hydrologically heterogeneous and thus should be modeled that way.

### Professional Qualifications

3. My qualifications to make this declaration are described in my qualifications summary, a copy of which is appended hereto as **Exhibit A**. I have also provided a list of publications on Jurassic geology that I have authored, co-authored or contributed to since 1984; it is appended hereto as **Exhibit B**. I have a B.A. degree (Anthropology) from the University of New Mexico (1976), a M.S. degree (Geology) from Yale University (1979), and a Ph.D. in Geology, also from Yale University (1984).

4. As my publications list (see Exhibit B) demonstrates, I have studied the stratigraphy, sedimentology, paleontology, and paleogeography of Jurassic rocks in New Mexico and adjacent states (especially Arizona, Utah, and Colorado) since 1983. My research has

resulted in more than 100 publications on these Jurassic rocks, and in a revised regional Jurassic stratigraphy incorporated into the *Geologic Map of New Mexico* published in 2003 by the New Mexico Bureau of Geology. I have extensive field experience studying the Jurassic rocks of the Grants uranium region of west-central New Mexico, and co-authored the most recently published synopsis of the Jurassic geology of that area (Lucas and Heckert, 2003). In the course of my research on the Jurassic rocks in west-central New Mexico, I have reviewed hundreds of published and unpublished articles, reports, monographs and theses. I have mapped Jurassic rocks in west-central New Mexico, measured numerous stratigraphic sections in these rocks and examined thousands of rock samples from their outcrops. In 2003, I co-organized the 54<sup>th</sup> Annual Field Conference of the New Mexico Geological Society to further educate more than 100 geologists on the Jurassic geology (and other aspects of the geology) of west-central New Mexico. I also have knowledge of the principles and methods of groundwater geology. In particular, I understand the relationship between lithology, permeability and groundwater flow in the subsurface.

5. I have testified in this proceeding once before, giving an expert affidavit on the interpretation of the depositional environment of the Westwater Canyon Member of the Jurassic Morrison Formation in the Church Rock area on May 20, 1999. (See, Response Affidavit of Dr. Spencer G. Lucas (May 20, 1999), attached as Exhibit 3 to Intervenors' Joint Response to HRI's and the NRC Staff's Responses to the Presiding Officer's April 21, 1999 Memorandum and Order (Questions) (May 25, 1999).) A copy of my May 1999 affidavit is appended to this declaration as **Exhibit C**.

## Materials Reviewed and References Cited

6. In preparing this declaration, I reviewed relevant portions of the Nuclear Regulatory Commission's ("NRC's") *Final Environmental Impact Statement to Construct and Operate the Crownpoint Uranium Solution Mining Project, Crownpoint, New Mexico*, NUREG-1508, BLM NM-010-93-02, BIA EIS-92-001 ("FEIS"), February, 1997 (Hearing Notebook ["NB"] 10; ACN 9703200270); the source materials license (SUA-1508) issued to HRI by the NRC on January 5, 1998 (NB 11; ACN 980116066); HRI's Consolidated Operations Plan ("COP"), Rev. 2.0, August 15, 1997 (NB 10.3; ACN 9708210179), and relevant portions of HRI's Churchrock Project Revised Environmental Report ("CRPRER"), March 16, 1993 (NB 6.1 and 6.2; ACN 9304130421). I also reviewed my May 20, 1999 written testimony and the affidavit of Frank Lee Lichnovsky (February 19, 1999) ("Lichnovsky Testimony"), attached as an unnumbered exhibit to HRI's Response to Intervenors' Presentation on Groundwater Issues (February 19, 1999). In this declaration, I cite several references to the published geologic literature, and these citations are listed below.

Asquith, G. and Gibson, C., 1982. Basic well log analysis for geologists. Tulsa, American Association of Petroleum Geologists, 216 p.

Campbell, C. V., 1976. Reservoir Geometry of a Fluvial Sheet Sandstone. American Association of Petroleum Geologists Bulletin, 60:1009-1020.

Condon, S. M. and Peterson, F., 1986. Stratigraphy of Middle and Upper Jurassic rocks of the San Juan Basin: Historical perspective, current ideas, and remaining problems: American Association of Petroleum Geologists Studies in Geology 22:7-26.

Cowan, E. J., 1991. The large-scale architecture of the fluvial Westwater Canyon Member, Morrison Formation (Upper Jurassic), San Juan Basin, New Mexico: SEPM Concepts in Sedimentology and Paleontology 3, p. 80-93.

Gregory, H. E., 1938. The San Juan Country: A Geographic and Geologic Reconnaissance of Southeastern Utah. U. S. Geological Survey Professional Paper 188: 1-123.

Hackman, R. J. and Olson, A. B., 1977. Geology, structure, and uranium deposits of the Gallup 1 X 2 quadrangle, New Mexico and Arizona: U. S. Geological Survey, Map I-981, scale 1:250,000.

Hilpert, L. S., 1969. *Uranium Resources of Northwestern New Mexico*. U.S. Geological Survey Professional Paper 603.

Hydro Resources, Inc., 2000. Church Rock Section 8/Crownpoint Process Plant Restoration Action Plan, November 17.

Lucas, S. G. and Heckert, A. B., 2003. Jurassic stratigraphy in west-central New Mexico: New Mexico Geological Society Guidebook 54: 289-301.

Owen, D. E. and Owen, D. E., Jr., 2003. Stratigraphy of the Dakota Sandstone and intertongued Mancos Shale along the southern flank of the San Juan Basin, west-central New Mexico: New Mexico Geological Society Guidebook 54: 325-330.

Peterson, R. J., 1980. Geology of Pre-Dakota Uranium Geochemical Cell, Section 13, T16N, R17W, Church Rock Area, McKinley County, in: *Geology and Mineral Technology of the Grants Uranium Region 1979*. C. A. Rautman, ed., New Mexico Bureau of Mines and Mineral Resources, Memoir 38, pp. 131-138.

Robertson, J. F., 1990. Geologic map of the Thoreau quadrangle, McKinley County, New Mexico: U. S. Geological Survey Map GQ-1675, scale 1:24,000.

Turner-Peterson, C. E. and Fishman, N. S., 1986. Geologic synthesis and genetic models for uranium mineralization in the Morrison Formation, Grants uranium region, New Mexico: AAPG Studies in Geology 22: 357-388.

United Nuclear Corporation, 2003. Northeast Church Rock Mine Site Assessment, prepared by MWH (Steamboat Springs, Colorado), July.

I refer to various maps, charts, pictures and stratigraphic sections throughout this declaration. For convenience of review, I have assembled these figures in **Exhibit D** attached hereto. Captions for each of the figures in **Exhibit D** are listed in Addendum 1, which appears at the end of this declaration.

#### Professional Opinion, Background and Analysis

7. Based on my review of the materials cited above and on original field studies I

performed in support of this declaration, I conclude that (1) at all three of HRI's proposed subsurface mine sites, there is no aquitard, that is, a groundwater confining layer, below the Westwater Canyon Member, the rock unit to be mined; (2) at HRI's proposed Church Rock Section 17 mine, there is no aquitard immediately above the Westwater Canyon Member; (3) at HRI's proposed Unit I mine site near Crownpoint, there may be no aquitard immediately above the Westwater Canyon Member; (4) at HRI's proposed *in situ* leach ("ISL") mine sites (Section 17, Unit I and Crownpoint), there is insufficient confinement of groundwater, so it is highly likely that the mining will lead to impairment of groundwater quality in aquifers stratigraphically below and stratigraphically above the mined interval; and (5) the Westwater Canyon Member is heterogeneous locally at proposed ISL mining sites in Church Rock and Crownpoint.

Accordingly, I conclude that HRI has not demonstrated that it will be able to keep mining fluids from escaping into underlying and overlying aquifers at the Section 17, Unit I and Crownpoint sites, thereby threatening contamination of underground sources of drinking water. Furthermore, the heterogeneity of the Westwater Canyon Member at the scale of the solution mining sites is undeniable, not only in light of the extensive site-specific literature, but also because small-scale channeling is clearly visible in the field at the Westwater's outcrop a short distance from the proposed Section 17 mine.

8. For the purposes of clear discourse, allow me to review some basic geologic terminology and classifications. Sand particles have a diameter of 2 millimeters ("mm") to 1/16 mm, silt particles have a diameter between 1/16 mm and 1/256 mm and clay particles are smaller than silt. Shale is a laminated sediment in which the constituent particles are predominantly of clay size. ("Laminated" means that the sediments are pressed into thin layers.) It includes indurated (meaning, hardened), laminated or fissile (meaning, easily broken up) claystone, which

sometimes contains particles of silt or sand size. Shale is impermeable (unless fractured) and thus generally confines the flow of water. In other words, shale is relatively impervious to water and can be described as an “aquitard,” that is, a rock layer that retards or forms a barrier to vertical movement of water.

9. Sandstone is a cemented or otherwise compacted detrital sediment composed of sand-size grains, usually grains of quartz. Sandstone is characteristically permeable, meaning that water can flow through void spaces between the grains of sand; thus, sandstone generally does not confine the flow of water. In other words, sandstone is rarely, if ever, an aquitard. Indeed, in the subsurface, sandstone is very often an aquifer — a zone capable of producing water.

10. Siltstone is a very fine-grained and consolidated rock composed of particles of silt. Most geologists now consider siltstone to be similar to sandstone but finer grained and more compact; it is a rock type intermediate in properties between sandstone and claystone (or shale). Therefore, siltstone is of intermediate permeability and its ability to confine groundwater flow is also between that of sandstone (little or no confinement) and claystone or shale (generally good confinement).

11. HRI proposes to leach uranium from four subsurface locations: (1) Southeast quarter of Section 8, T16N, R16W (referred to as “Church Rock Section 8” or “Section 8”); (2) northeast quarter of Section 17, T16N, R16W (referred to as “Church Rock Section 17” or “Section 17”); (3) portions of Sections 15-16, 22-23, T17N, R13W located about 2.5 miles west of Crownpoint (referred to as “Unit I”); and (4) the south half of Section 24, T17N, R13W (referred to as the “Crownpoint” site). These locations are shown in **Figure 1**, which is contained

in Exhibit D appended hereto. My comments that follow address the geologic regime at the Section 17, Unit I and Crownpoint sites.

**A. Recapture “Shale” is Not a True Shale, and Therefore, Not a Confining Layer**

12. To assess whether the Recapture Member of the Morrison Formation is a real confining layer for ISL mining in the overlying Westwater Canyon Member, I will first review the lithologic composition of the Recapture and how perception of it has changed over the past 70 years. H. E. Gregory named the “Recapture Shale Member” in 1938 for rocks exposed near Bluff, Utah. Gregory described the unit as composed of shale and sandstone. Subsequent workers realized that very little of the Recapture Member is shale; instead, the rock unit is mostly sandstone and siltstone, with only minor beds (a few percent of the unit) of clay (or, “shale”).

13. A review of the last half century of published literature reveals that no experienced geologist considers the Recapture Member to consist of shale. That is why it has long been called Recapture Member — the term “shale” was dropped decades ago. For example, Condon and Peterson (1986, at 21) provide the following description of the Recapture: “The Recapture Member is a heterogeneous unit consisting of interbedded sandstone, siltstone, mudstone, claystone and limestone that characteristically weathers to poorly exposed, color-banded slopes.” Robertson’s (1990) geologic map of the Thoreau quadrangle described the “Recapture Member” as consisting of an upper half of “interbedded thick bed of fine- to coarse-grained, poorly sorted and friable, . . . trough crossbedded fluvial sandstone . . . [and] mudstone, siltstone, and claystone of overbank deposits” and a lower half “of interbedded, thin, . . . fine-grained beds, including . . . clayey siltstone, . . . fine- to very fine-grained sandstone and white platy limestone, mainly of lacustrine and eolian origin.” See, Exhibit D, Figure 6. Even though

the lower part of the Recapture “contains relatively few medium- to coarse-grained sandstone lenses of fluvial origin” (*ibid.*), Robertson describes the Recapture as having the characteristics of a highly varied sedimentary rock that has the “composition . . . and character of the overlying Westwater Canyon Member . . . [and] [i]ntertongues with underlying sandstone unit.” *Ibid.* The most recent published summary of Jurassic stratigraphy in west-central New Mexico by Lucas and Heckert (2003, at 295; reprinted in its entirety and attached hereto as **Exhibit E**) describes the Recapture Member as “finer-grained sandstones and siltstones” up to 36 meters (“m”) (or, 118.1 feet) thick. Thus, the idea that the Recapture Member is “shale” is an old one that began in the 1930s but was long ago abandoned. Geologists have known for decades that the Recapture Member is mostly sandstone and siltstone; it contains little or no shale at a localized level.

14. HRI, in several parts of its application (see, e.g., COP Rev. 2.0 at 78; CRPRER, Figure 2.6-13 at 81 and Figure 2.7-14 at 105) and in the Lichnovsky Testimony (at 14-16 and Figures 16 and 18), refers to the Recapture as a shale. This is incorrect and indicates that HRI is basing its understanding of the lithology of the Recapture Member on outdated research.

#### **B. Outcrop Analogue Studies Conducted for This Declaration**

15. The uranium orebodies at all four locations are in the Westwater Canyon Member of the Morrison Formation at a substantial depth of hundreds of feet below land surface. At the surface at both locations, Upper Cretaceous rocks are exposed. Thus, the geology of the Jurassic rocks (the exploration, drilling and mining targets) at HRI’s proposed mine sites is primarily known directly from subsurface geological data based on geophysical well logs. Geophysical logs are the print-outs of readings of instruments lowered into a drill hole to determine rock properties such as porosity, permeability and water saturation, and therefore allow inferences as

to the lithology of the rocks encountered in drilling. Fortunately, HRI's proposed mine sites are geographically close to surface exposures, called "outcrops," of the Jurassic rocks that occur at the locations of the proposed mines. This is because the HRI sites are located in an area of generally north-dipping (tilted) strata so that the Jurassic rocks deep in the subsurface at the HRI sites are also exposed at the surface to the south of the mine sites.

16. Geologists have long known that much more can be learned from the study of rock outcrops than can be learned from subsurface data from boreholes and geophysical well logs. For this reason, one of the basic methods of geological exploration for mineral or energy resources is to study outcrop analogues of a subsurface mining prospect. An outcrop analogue is a surface exposure of a rock unit geographically close to, and geologically similar to, that same rock unit where it is a subsurface exploration and mining target. HRI gives no indication in its application that it studied the obvious outcrop analogues near its proposed subsurface mining sites. I did, and the results of my studies are described and discussed in the paragraphs that follow.

17. The method of outcrop analogue study involves determining the lithology and geometric relationships of rocks at the surface that are of significance to mining in the subsurface. In this case, the subsurface Jurassic rock units above and below the Westwater Canyon Member are the rocks of significance to the subsurface mining. I conducted two outcrop analogue studies in the first week of January 2005 in support of this testimony. Using Hackman and Olson's (1977) U. S. Geological Survey 1:250,000 geological map of the Gallup quadrangle, I located the closest Jurassic outcrops to the proposed mining sites in the Church Rock and Crownpoint areas. I then traveled to and through those areas, photographing the Jurassic outcrops, hiking over the entire geologic section, and measuring and examining each rock layer

at face level. This technique allowed me to observe in detail the lithology and geometric relationships of the Jurassic rocks of significance to the subsurface mining sites. Using these techniques, I determined that the nearest outcrops to the Section 17 mine site are in Section 36, T16N, R17W and Section 1, T15N, R17W. These sites are between three and four miles south of Section 17. See, Exhibit D, Figure 1. I identified the nearest outcrops to the Unit I and Crownpoint mine sites as located in Section 8, T14N, R12W. This area is about 15 miles south of Crownpoint. Ibid.

18. My study of these outcrop analogues (Exhibit D, Figures 2 through 4) indicates that HRI's analysis and interpretation of the subsurface Jurassic geology at the proposed mine sites are incorrect. HRI's analysis and interpretation concludes that at the subsurface mining locations, the uranium-bearing zone, which is the Westwater Canyon Member of the Morrison Formation, is between two shale units that are aquitards: the Brushy Basin Member (above) and the Recapture Member (below). See, e.g., CRPRER at 104-106, including Figure 2.7-14 and Table 2.7-1. My analysis of the outcrop analogues, and my reanalysis of the Lichnovsky Testimony (see, ¶¶ 27-35 below), which interpreted the subsurface geology of the Section 17 mine site, indicates no aquitard confinement under the Westwater Canyon Member at HRI's proposed mine sites, and little or no aquitard confinement above the Westwater Canyon Member at these sites.

**(1) Section 17 — Outcrop Analogy Study A**

19. I will refer here to the Jurassic outcrops near the Section 17 mine site as Outcrop Analogue A, which are depicted graphically and in photos in Exhibit D, Figures 2 and 3, respectively. The photos in Figure 3 are Jurassic outcrops with excellent exposures along State

Highway 566 between Church Rock Village on the south and White Rock Mesa in Section 1, T15N, R17W and Section 36, T16N, R17W on the north. See, Exhibit D, Figure 1. Based on my observations, photographs and knowledge of the stratigraphy in this area, I drew a stratigraphic section of the Jurassic rocks at these locations; it is shown on the left side of **Exhibit D**, Figure 2. This section consists of the following units, in ascending stratigraphic order:

- a. Cow Springs (or Bluff) Sandstone, about 200 feet thick, consisting mostly of flat-bedded, friable sandstone. (“Friable” means something that is easily crumbled or crushed into powder.) See, Exhibit D, Figure 3.4.
- b. Recapture Member, 50 feet or less of red, flaggy-bedded sandstone and siltstone. (“Flaggy” means rocks that are easily split into flat pieces; see, Exhibit D, Figure 3.1.)
- c. The upper Cow Springs Sandstone, approximately 100 feet of steeply crossbedded, very friable sandstone. (Some geologists refer to the Cow Springs Sandstone at these locations as the Acoma Tongue of the Zuni Sandstone or the upper Recapture Member. The names geologists give to local rock formations are less important than the geologic descriptions of those formations.)
- d. The Westwater Canyon Member, 100 feet to 250 feet of crossbedded sandstone, in some places conglomeratic, meaning that some layers of the Westwater are composed of many different rock types, including gravels and pieces of sandstones and siltstones indicative of their fluvial (i.e., streambed) origin.
- e. Main body of the Dakota Sandstone, a Cretaceous-aged formation containing sandstone, shale and coal up to 150 feet thick. See, Exhibit D, Figure 3.5.

20. Outcrop Analogue A (Exhibit D, Figure 2) thus shows the Dakota Sandstone resting directly on the Westwater Canyon Member; no shale of the Brushy Basin Member is present, so no aquitard overlies the Westwater Canyon Member at Outcrop Analogue A. Furthermore, the Westwater Canyon Member at Outcrop Analogue A rests directly on Cow Springs sandstone, so no aquitard directly underlies the Westwater Canyon Member here. The complete absence of the Recapture in the Church Rock area is recognized in the FEIS, which cites papers by Hilpert (1969)<sup>1</sup> and Peterson (1980), who separately concluded that the “Recapture Member does not occur and that the Westwater Canyon Member lies directly on the Cow Springs Sandstone.” FEIS at 3-18, citing Peterson, 1980.

21. Outcrop Analogue A also reveals an important geometric relationship between the Recapture Member and Cow Springs Sandstone (Exhibit D, Figures 2 and 3.2). This is the lack of continuity of the Recapture Member on the outcrop scale (hundreds of feet or less) and regionally (over miles). Thus, the Recapture Member pinches out (disappears) into the Cow Springs at many locations. One such location is displayed well along State Highway 566, as shown in two photographs, Figures 3.2 and 3.3 (Exhibit D). Here, over a lateral distance of a few tens of feet, the Recapture thins dramatically to disappear between the lower Cow Springs and upper Cow Springs sandstones. This means that the Recapture is not a continuous stratigraphic unit, but instead frequently disappears over short outcrop distances. Regionally, this

---

<sup>1</sup> Hilpert's 1969 paper showed the “Recapture Member” intertonguing with the Cow Springs Sandstone northeast of the Gallup area, based on electric logs of uranium exploration holes drilled in the late 1950s. Hilpert's Figure 11 was reprinted as Exhibit N to Michael Wallace's January 8, 1999, written testimony (hereinafter “Wallace 1999 Testimony”), which was, attached as Exhibit 3 to Intervenor's Revised Written Presentation in Opposition to Hydro Resources, Inc.'s Application for a Materials License With Respect to Groundwater Protection (January 18, 1999). Mr. Wallace testified that according to Hilpert, “much of the mining zone in section 8 is a region where the Recapture has virtually disappeared, such that the Cow Springs Aquifer comes into nearly direct contact with the Westwater. This is demonstrated by his Figure 11, . . . which uses many of the same Phillips borehole logs that HRI used.” Wallace 1999 Testimony at 63.

geometric relationship is also well documented (see, Lucas and Heckert, 2003, Figure 6; attached hereto as **Exhibit E**).

22. The very short distance of 3 to 4 miles between Outcrop Analogue A and the proposed Section 17 mine (**Exhibit D**, Figure 1) makes it highly likely that the Jurassic geology at the mine site is identical to the outcrop analogue. Indeed, my reanalysis of Lichnovsky's testimony (see below), which includes subsurface data from near the mine site, supports the conclusion that the Jurassic geology of the Section 17 mine subsurface is the same as at Outcrop Analogue A. This means that at the mine site, no aquitards confine the Westwater Canyon Member.

23. Further confirmation of my interpretation of the subsurface Jurassic geology at the proposed Section 17 mine site is provided by United Nuclear Corporation's "Northeast Church Rock Mine Site Assessment" (UNC 2003). This mine site is in Section 35, T17N, R16W, about 3 miles northeast of the Section 17 mine site (**Exhibit D**, Figure 1). The assessment includes as its Figure 3 a stratigraphic column that shows the Westwater Canyon Member resting directly on sandstone of the Cow Springs Sandstone. A copy of this depiction of the stratigraphic column of the main mine shaft is appended hereto as Figure 10 in **Exhibit D**. Thus, no aquitard underlies the Westwater Canyon Member both north and south of the proposed section 17 mine site.

24. The stratigraphic column of the Northeast Church Rock Mine Site also shows a thin mudstone- (or, claystone-) dominated Brushy Basin Member above the Westwater Canyon Member. UNC 2003, Figure 3; see, also, **Exhibit D**, Figure 10. This indicates that a thin aquitard overlies the Westwater Canyon Member at that site, but it is much thinner than Lichnovsky's "Brushy Basin Member" at the section 17 site (Lichnovsky Testimony, Figure 16). Thus,

Lichnovsky's identification of a thick Brushy Basin Member in the well logs from Section 17 and 8 (see below) is not consistent with regional and steady thickening of the Brushy Basin Member northward.

**(2) Unit 1 and Crownpoint Sites — Outcrop Analogue Study B**

25. I conducted Outcrop Analogue Study B to compare HRI's description of the subsurface geology at the Unit I and Crownpoint sites with the same geologic section at its outcrop. I used the same techniques for locating the Jurassic outcrop south of Crownpoint as I used in the Church Rock area, and described in ¶ 17 above. These are outcrops located northeast of Thoreau, N.M., just east of State Highway 371 in the NE1/4 Section 8, T14N, R12W. See, Exhibit D, Figures 1, 2, and 4. Here, the Jurassic rocks relevant to the proposed mine sites west of Crownpoint are very well exposed along the flank of an unnamed mesa (Exhibit D, Figure 4.1). The relevant Jurassic section I constructed from my fieldwork and information in the literature is shown in Figure 2 of Exhibit D, and is listed in ascending order as follows:

- a. Lower Cow Springs (or Bluff) Sandstone, about 180 feet thick, mostly crossbedded and friable sandstone.
- b. Recapture Member, up to 160 feet thick, mostly crossbedded sandstone, flat-bedded sandstone and clayey siltstone. See, Exhibit D, Figures 4.2 and 4.3.
- c. Westwater Canyon Member, about 190 ft of crossbedded and conglomeratic sandstone. See, Exhibit D, Figures 4.1.
- d. Brushy Basin Member, about 70 feet thick, mostly sandstone, with some beds of siltstone and claystone. Ibid.

- e. Main body of Dakota Sandstone (Cretaceous), sandstone and siltstone about 130 feet thick. Ibid.

26. Outcrop Analogue B shows the Brushy Basin Member overlying the Westwater Canyon Member, though the Brushy Basin Member here is mostly sandstone and thus not a particularly good aquitard. Furthermore, the Westwater Canyon Member here overlies a sandstone-dominated Recapture Member that is not a shale aquitard. Thus, the Westwater Canyon Member at Outcrop Analogue B is not encased by two shale aquitards. This suggests that the Westwater Canyon Member at the proposed Crownpoint mining site also is not encased by shale aquitards.

27. The analysis of Outcrop Analogue B (Exhibit D, Figure 4) can be applied to the geology of the Unit I and Crownpoint sites as described in the FEIS. The FEIS (at 3-8) confirms the *geologic* description of the Recapture Member east of the Gallup “as one of the most variable stratigraphic units in the area[,] . . . a sequence of interbedded siltstone, mudstone and sandstone strata....widely believed to interfinger with the underlying Cow Springs Sandstone....” In the Crownpoint-Unit 1 area, the Recapture “mudstone unit” is reported to be 250 feet to 260 feet thick. FEIS at 3-12, 3-18.

28. Yet, the FEIS demonstrates that there was confusion among the NRC Staff about the correct interpretation of the geologic characteristics of the Recapture Member at the proposed mining sites. For instance, in the description of the geology in the Church Rock area, the Recapture is called a “Shale” (FEIS at 3-18) and is depicted in a stratigraphic column of the Church Rock site as a shale. Ibid., Figure 3.7 at 3-19. When the discussion turns to the hydrology of the Unit 1 and Crownpoint sites, the FEIS refers several times to the “Recapture Shale” (see,

e.g., 3-25, 3-29, and 3-35), even though its own description of the unit indicates the Recapture Member is *not* a shale.

29. The Westwater Canyon Member is described in the FEIS (at 3-8) as “interbedded fluvial red, tan, and light gray arkosic sandstone, claystone, and mudstone....the major water-bearing member of the Morrison.” The stratigraphic column for the Unit I and Crownpoint sites in the FEIS (Figure 3.5 at 3-14; attached hereto as Figure 11 in **Exhibit D**) is consistent with these descriptions, and thus indicates a mixed sandstone-mudstone Recapture Member that interfingers with the Cow Springs Sandstone, immediately overlain by a sandstone-dominated Westwater Canyon Member. The FEIS thus presents the Recapture Member as a rock unit that is not an aquitard at the Unit 1 and Crownpoint sites. Indeed, the only geological difference between the Unit 1 and Crownpoint sites and Outcrop Analogue B (**Exhibit D**, Figure 4.1) is that the Brushy Basin Member has more mudstone (claystone) at the Unit 1 and Crownpoint sites than at Outcrop Analogue B. This suggests that the Brushy Basin Member may be a better aquitard at those sites than it is at Outcrop Analogue B.

**C. Absence of a Confining Unit Under the Westwater Canyon Member at Section 17: HRI’s Misinterpretation of Geophysical Well Logs**

27. I have reviewed and evaluated the testimony of Frank Lee Lichnovsky (February 19, 1999). In ¶ 11 at 18-20, Lichnovsky claims that the “Recapture Shale” “consists of predominantly shale with discontinuous sandstone lenses” (his underlining). This is incorrect (see above) and, indeed, the opposite is the case — the Recapture is predominantly sandstone (and siltstone) with (minor) discontinuous shale lenses.

28. To support his claim, Lichnovsky refers to regional cross sections (such as his Figure 15) that generalize the differences between coarse-grained units, such as the Westwater

Canyon Member, and generally finer-grained units such as the Recapture Member. However, more accurate regional cross sections show the Recapture as dominantly sandstone (Exhibit D, Figure 5). Lichnovsky ignores the outcrop analogues detailed here and the detailed description of the Recapture Member provided in numerous publications and geological maps. A good example of these maps is Robertson's (1978) geologic map of the Thoreau quadrangle (Outcrop Analogue B is on this quadrangle), which describes a lithologically complex and heterogeneous Recapture Member, mostly composed of sandstone (Exhibit D, Figure 6).

29. Lichnovsky also relies on his own interpretation of geophysical logs that penetrated the Recapture Member near the Section 17 mine site. He claims these logs indicate at least 100 feet of "Recapture shale" underlie the Westwater Canyon Member in sections 8-17, T16N, R16W. In particular, Lichnovsky reviews the geophysical log for hole 2.8/17.7, which was reproduced as Figure 16 of his February 1999 testimony and is referenced in the FEIS at 3-35. Hole 2.8/17.7 is located in the south-central part of Section 8, about 900 feet west of the proposed Section 8 mining area, and about 750 feet northwest of the Section 17 mining area. Lichnovsky, in his testimony at 15, states that "where impermeable shale is present the [spontaneous potential] curve falls to the right and in the vernacular of geologic interpretation, forms the 'shale line'." I agree, and I know Lichnovsky would agree that establishing a "shale [base]line" is one of the first steps in geophysical well log interpretation.

31. However, my re-examination of the logs attached to Lichnovsky's February 1999 Testimony reveals that Lichnovsky misinterpreted them. To establish a shale baseline for geophysical log 0.2.8/17.7 (Lichnovsky Testimony, Figure 16), I used the Whitewater Arroyo Shale Member of the Mancos Shale (~460-535 feet depth in the log). I folded this log so that the portion labeled "Whitewater Arroyo Shale" is juxtaposed with the portion labeled "Recapture

Shale,” and then drew a vertical line labeled “shale baseline.” My resulting graphic is appended as Figure 7 in Exhibit D. Lichnovsky correctly identifies the Whitewater Arroyo unit as mostly composed of shale, and its spontaneous potential (“SP”) values are nearly consistent and positive, indicating that the Whitewater Arroyo Shale is almost entirely shale. This can be confirmed by examination of the Whitewater Arroyo Shale on an outcrop approximately 1 mile south of the well site. When we compare the Whitewater Arroyo Shale SP curve with that for the Recapture Member (~930-1110 feet depth by Lichnovsky’s labeling of his Figure 16; see Figure 7 in Exhibit D), the following facts become evident:

- The SP curve for the Recapture Shale is mostly offset to the left from the Whitewater Arroyo Shale curve, indicating the Recapture is almost totally coarser-grained than the Whitewater Arroyo Shale.
- There is much more fluctuation (much greater and more rapid deflections) in the Recapture SP curve than in the Whitewater Arroyo Shale SP curve, suggesting the Recapture is not as lithologically homogenous as the Whitewater Arroyo Shale.
- And, most significant, the Recapture SP values and frequency of deflection correspond well to other intervals of the log interpreted as sandstone by Lichnovsky; for example, the Westwater Canyon Sandstone interval between ~710-780 ft in the log (but missing from my Figure D.7), and what Lichnovsky calls “Cow Springs SS” between 1110 and 1130 feet on the log.

32. Lichnovsky’s interpretation of lithology from the log is internally inconsistent. A consistent and correct interpretation of the log identifies the “Recapture Shale” interval of the log (940-1110 feet) as almost wholly sandstone, and raises the question whether or not these strata are wholly (as Lichnovsky concludes) or partly or at all Recapture Member. Thus, my interpretation of the log, consistent with the observations made at Outcrop Analogue A, suggests that most of this interval is not Recapture Member but instead fine-grained and permeable sandstone of the “upper Cow Springs Sandstone” (Acoma Tongue of the Zuni Sandstone).

33. If any Recapture Member is present in the well, it may be the busy (many large deflections) interval with relatively positive SP values between about 1080 and 1100 feet. The many deflections suggest an interbedding of sandstone and siltstone lithologies as is seen in the Recapture Member at Outcrop Analogue A. Also, note that Lichnovsky identifies some thin but large deflections in the log as "THIN BEDDED LIMESTONE LAYERS NO PERMEABILITY." (This label is shown under "950" in the middle of my juxtaposed log in Exhibit D, Figure 7.) There is, however, no reason to conclude this, as the SP (and resistivity) curves here are just like those of intervals identified by Lichnovsky as sandstone elsewhere in the log.

34. I want to emphasize here a basic concept stated by Asquith and Gibson (1982, at 28) in their book on well-log analysis: "*Permeable zones are indicated where there is SP deflection from the shale baseline*" (emphasis added). Clearly, the interval identified by Lichnovsky as "Recapture Shale" in geophysical log 8-02.8/17.7 is mostly deflected (negative deflection) from the shale baseline. Therefore, it is a zone of permeability.

35. A similar analysis of the geophysical log for drill hole #53/41 (Lichnovsky Testimony, Figure 18) reveals an even larger deflection of the "Recapture Shale" from the shale baseline. This also indicates that the Recapture interval in this well is not shale, but almost wholly permeable sandstone. Hole #53/41 is located in the northeastern quarter of Section 17 inside the proposed mining area. See, CRPRER, Figure 2.6-5 at 73. I can only conclude that although Lichnovsky was able to state basic principles of well-log analysis, he failed to apply these principles to correctly interpret the well logs presented in his own testimony.

**D. Brushy Basin May Not Be Present at Section 17**

36. Outcrop Analogue A also raises serious questions about Lichnovsky's identification of the "Brushy Basin Shale" as the rock unit above the Westwater Canyon Member. On geophysical log 8-02.8/17.7 (Lichnovsky Testimony, Figure 16), the interval between 615 and 700 feet, which is labeled "Brushy Basin," is an interval of interbedded sandstone and shale. Again, his identification on this log of the Brushy Basin as a "thin bedded limestone [having] no permability [sic]" in this interval lacks a factual basis.

37. I made the same inspections of the geophysical log for hole #53/41, which was attached to Lichnovsky's 1999 testimony as Figure 18 and is located in Section 17. The interval labeled "Brushy Basin Shale" on Lichnovsky's Figure 18 is between 485 feet and 550 feet and is also an interbedded sandstone and shale. This "Brushy Basin Shale" interval, however, very much resembles the lower part of the Dakota Sandstone in Outcrop Analogue A, located about 2.5 miles southwest of Section 17. As I show in Figure 3.5. in Exhibit D, the Dakota rests directly on the Westwater Canyon Member; no Brushy Basin Member intervenes. Based on my field observations and on the drawing of the Dakota Sandstone in the 2003 paper by Owen and Owen (see, Exhibit D, Figure 8), the Dakota is a unit made up mostly of sandstone with some clay and coal beds. For Lichnovsky's interpretation of the data in the two geophysical logs to be correct, he would have had to explain how the Brushy Basin Member could increase in thickness from 0 feet at Outcrop Analogue A to about 70-85 feet at the two exploration holes, a distance of about three miles. But I find no such explanation in his February 1999 testimony.

38. Furthermore, the "Brushy Basin Shale" Lichnovsky identifies in the drill hole logs looks to me to be very sandy (that is, it's made up of at least 50 percent sand) and certainly is not

the shale-dominated unit normally seen on outcrop. At Outcrop Analogue A, I observed the main body of the Dakota Sandstone to be about 120 feet thick, and this agrees with the section drawing by Owen and Owen (2003) that I appended as Figure 8 in Exhibit D. This suggests that most if not all of the unit Lichnovsky identified as "Brushy Basin Shale" in the logs is not the Brushy Basin Member, but the Dakota. Since I have no technical reason to believe that the Dakota thickness does not remain relatively constant between Outcrop Analogue A and the holes in sections 8 and 17, then only the lower 40 feet of the "Brushy Basin Shale" might be Brushy Basin Member in the Section 8 hole. Lichnovsky Testimony, Figure 16. In the Section 17 hole, the entire Dakota and Brushy Basin sequence as labeled by Lichnovsky in his Figure 18 is approximately 130 feet. This means that little if any of the "Brushy Basin Shale" may be present, and it is likely that all the strata so identified in this hole actually belong to the Dakota Sandstone.

39. Furthermore, support for the conclusion that no significant aquitard overlies the Westwater Canyon Member in the Section 17 and Section 8 boreholes comes from the lithofacies map of the Brushy Basin Member published by Turner-Peterson and Fishman in 1986. I have reproduced this diagram as Figure 9 in Exhibit D. This map indicates that Brushy Basin strata in the vicinity of the two boreholes are sandstone-dominated. Outcrop Analogue A, the geophysical logs of the two boreholes, and regional studies of the Brushy Basin Member indicate there is either no Brushy Basin Member present at Section 17 or there is a sandstone-dominated Brushy Basin Member. Most, if not all, of the interval Lichnovsky identified as Brushy Basin Member in these boreholes is instead a mixed sandstone, shale and coal interval of the main body of the Dakota Sandstone. This is a permeable unit, and not a confining unit, or aquitard.

**E. The Westwater Canyon Member is heterogeneous locally at proposed ISL mining sites in Church Rock and Crownpoint.**

40. An important issue concerns the geological composition of the Westwater Canyon Member and the relationship of its composition to permeability, porosity and the flow of groundwater through that rock unit. To address this issue I have relied on my own field observations and my knowledge of the past and recent literature on the Westwater Canyon Member depositional history. Prominent in the literature is the seminal paper by E. J. Cowan (1991), titled "The large-scale architecture of the fluvial Westwater Canyon Member, Morrison Formation (Upper Jurassic), San Juan Basin, New Mexico" published in *SEPM Concepts in Sedimentology and Paleontology*, no. 3, p. 80-93. I previously reviewed and discussed Cowan's research in my May 20, 1999, testimony in Phase I of this proceeding (**Exhibit C**). Given the importance of Cowan's contribution to the modern understanding of the Morrison fluvial system in the Church Rock area, I have attached as **Exhibit F** the full Cowan paper.

41. Cowan's study was designed to reconstruct the fluvial (river) architecture of the Westwater Canyon Member of the Morrison Formation in west-central New Mexico. In a sedimentological study such as that of Cowan, an architectural element is a morphological subdivision of a particular depositional system that emphasizes the three dimensional geometry of the facies associations. In other words, the term architecture is used by sedimentologists to mean the three-dimensional geometry of a rock body formed in a particular environment. Indeed, both the text and the illustrations of Cowan's article (see, especially, Cowan's Figure 18, reproduced here as Figure 12 in **Exhibit D**) make it clear that the goal is to reconstruct, in three dimensions, the river system that deposited the Westwater Canyon Member.

42. Cowan (1991) re-evaluates an important study of Westwater Canyon Member deposition by Campbell (1976), who concluded that deposition took place in channel systems 1.6

kilometers ("km") to 34 km wide by a braided river system composed of many smaller channels with widths of 30 meters ("m") to 366 m. Cowan argues that the channel systems identified by Campbell are not primary depositional features, but instead are "post-depositional aquifer conduits, or permeability-pathway components" (Cowan, 1991 at 80; see, Exhibit F). Cowan concludes that Westwater Canyon deposition was in channel belts one to several kilometers wide composed of numerous, smaller channels. Cowan's article thus well documents the lithologic heterogeneity of the Westwater Canyon Member at the scale of the small channels (which are associated with lenticular bar and overbank deposits on the order of a few feet to tens of feet across) and the continuity of long, nearly linear channel belts. A modern analogy is the depositional development of the Rio Grande and upper middle reaches of the Mississippi River in the Midwest, as they change course and sediments accumulate, forming sandbars.

43. What must be appreciated is that at a "small scale" (channel widths of tens to a few hundreds of feet), the Westwater Canyon is a three-dimensionally very complex amalgamation of many coalesced channel, bar and overbank deposits. But, at a "large scale" (widths of thousands of feet to a few miles) the Westwater Canyon Member consists of long, discrete channel belts, just like those produced by modern-braided rivers. Thus, at the small scale the Westwater Canyon is lithologically heterogeneous, consisting of numerous, interlaced ribbon-like sandstone bodies and lenses of conglomerate and mudrock, but only at the large scale can each channel belt be superficially characterized as sandstone, because the majority of the Westwater Canyon Member is sandstone.

44. The braided, stacked and ribbon-like channels of the Westwater Canyon Member at the scale of the proposed mining sites can be seen in a plan map that accompanied HRI's Section 8 Restoration Action Plan (HRI, 2000, Attachment E-2-2). In this depiction of the ore-

bearing zones, which I have reduced from its original size and appended as Figure 13 in Appendix D, it is easy to see how eight of the nine separate ore “zones” are stacked on top of each other in the heterogeneous array that typifies the Westwater.<sup>2</sup> This is precisely the geological architecture of the Westwater described by Cowan and routinely accepted as fact among geologists (e.g., Condon and Peterson, 1986; Cowan, 1991; Lucas and Heckert, 2003; Peterson, 1980, and Turner-Peterson and Fishman, 1986) who have studied and published research on the Jurassic sedimentary sequence in the Church Rock area and elsewhere in the southern portion of the San Juan Basin in west-central New Mexico. This is because the ore zones generally correspond to ancient groundwater conduits, which generally correspond to the ancient channels.<sup>3</sup> The correspondence between the ore zones and the channels is not 100 percent as not all of the ancient channels necessarily became hosts to ore bodies.<sup>4</sup> In other words, sometimes the channel is larger than the ore body or it lacks an ore body. Hence, HRI’s map of the Section 8 ore zones is not much different than a map of the ancient channels of the Westwater Canyon river system, and corresponds well with and confirms Cowan’s model.

45. Cowan's article, along with the published literature and HRI’s plan map of the Section 8 ore zones,<sup>5</sup> thus supports the conclusion that there must be at least two levels of

---

<sup>2</sup> The ore zones are labeled, in descending order (i.e., from youngest to oldest, or top to bottom, in the geologic sequence), UA, LA, UB, LB, UC, ULC, LLC, UD, and MD+LD. HRI 2000, Table 1, § E.2a at second unnumbered page under Tab 2. The lowermost zone, MD+LD, is not visible on the map.

<sup>3</sup> The consensus among mineral geologists is that the uranium was deposited in the Westwater fluvial system long after the sediments were laid down by groundwater recharge, and the uranium ores settled in the vicinity of humic deposits in the buried channel sediments.

<sup>4</sup> HRI’s Mark Pelizza addressed this issue in his February 19, 1999, affidavit in support of HRI’s Response to the Intervenor’s Groundwater Presentation (February 19, 1999), but he did not explain the relationship between the geometry of the rocks and the ore zones.

<sup>5</sup> Curiously, a similar version of this map showing the stacked and braided ore zones does not appear in the Restoration Action Plans for Section 17, Unit 1 and Crownpoint. Such graphic depiction of the subsurface geology is critical to an accurate understanding of the geometry and complexity of the small-scale channels in the Westwater

permeability/porosity in the Westwater Canyon Member: (1) the small scale (averaging 100 feet or less) of complex conduits, and (2) the large scale (more than 1000 feet) conduits that correspond to the channel belts. There must also be a third scale of permeability as well, according to Cowan, at the scale of Campbell's (1976) channel systems, which is up to 20 miles wide. With these superimposed levels (scales) of permeability/porosity, small channels, which predominate at the level of HRI's proposed mining sites, have permeability and porosity characteristics that accelerate groundwater flow, a hydrogeologic feature diminished or lost at the large scale of groundwater flow in the regional framework of large channel belts.

46. The scale difference is extremely important because the small-scale channels in the Westwater Canyon Member are the easy, rapid and primary conduits for groundwater flow, which moves much more slowly at the large scale of the channel belts. Also note that subsurface geological studies can readily identify and define the large-scale channel belts but usually lack sufficient detail to accurately reconstruct the small-scale channels in the subsurface. HRI's subsurface studies certainly adhere to this conclusion; they lack sufficient detail to accurately reconstruct the small-scale channels (the primary groundwater conduits) in the subsurface at HRI's proposed mine sites.

47. Cowan's study is placed in a basinal context and examines in detail an outcrop belt characteristic of the Westwater Canyon Member. This is standard sedimentological procedure, and there is no reason to believe that Cowan's conclusions do not apply to the Westwater Canyon throughout its depositional extent. Indeed, Cowan's study area is just northeast of Gallup near Red Rock State Park, nearly in the same location as my Outcrop Analogue A study area, only 2 to 3 miles south of the proposed Section 17 mine and about 3

---

Canyon Member, and thus should have been provided in HRI's application and/or its RAPs for Section 17, Unit 1 and Crownpoint.

miles north of Church Rock Village. Any competent geologist would readily extend Cowan's conclusions into the Church Rock and Crownpoint areas, given the vast scale of the Westwater Canyon Member river system (see, Exhibit D, Figure 12).

48. I am further convinced of the heterogeneity of the Westwater Canyon Member at the scale of the small channels defined above in ¶ 44 based on the outcrop analogue study I conducted in the Church Rock area in January. Looking closely at the Westwater outcrops, they are obviously a stack of small-scale channels (up to a few meters thick, with lateral extents of a few tens of meters) separated in some cases by thin, lenticular mudstone units (see, for example, Exhibit D, Figures 3.4 and 3.5). This is exactly what Cowan described, and is thus exactly the geometry of the Westwater Canyon Member sandstone bodies that can be seen throughout the outcrop area in the Church Rock-Crownpoint region.

49. It is thus surprising that former Presiding Officer Peter B. Bloch, in evaluating the Lucas Phase I testimony (LBP-99-30<sup>6</sup> at 87), acknowledged the two levels of permeability/porosity in the Westwater Canyon Member identified by Cowan (the small-scale and large-scale channels discussed above), but concluded that it did not support the Intervenor's position that the Westwater is heterogeneous and should have been modeled as such for purposes of evaluation of hydrodynamic control of mining fluids. Bloch (Ibid., at 88) goes on to conclude that "on a larger scale the Westwater may be treated as homogeneous." In so doing, he not only failed to understand the conclusions of the Cowan study, but wrongly dismissed the Intervenor's description of the Westwater as highly channelized as "hypothesis" (Ibid.). As an expert<sup>7</sup> in the sedimentology of the Jurassic sequence in the Church Rock area, I vehemently disagree with this

---

<sup>6</sup> 50 NRC 77 (1999).

<sup>7</sup> Judge Bloch accepted me as an expert in Phase I of this proceeding. See, LBP-30-99 at 87, n.13.

conclusion. There is nothing hypothetical about the small-scale channelization of the Westwater — it is fact that can be observed and verified by any unbiased investigator, as I have done for this declaration.

50. To use an analogy, the channels of the Westwater Canyon Member are like the individual strings in a bundle of woven and braided strings that makes up a rope. From a great enough distance the rope (bundle of strings) can be viewed as homogeneous, as Judge Bloch saw it. But, this long distance view is irrelevant to the composition of the strings, their arrangement and the airspace around each string. In Cowan's model, each string is a conduit for water flow (small-scale channel), and so water will flow through each conduit in a complicated and convoluted pathway, especially because water can pass from one conduit to another where the conduits merge. Judge Bloch's conclusions ignore this and reveal a fundamental misappreciation on his part of Cowan's study and its implications for groundwater flow through the Westwater Canyon Member.

51. HRI's treatment of the Westwater Canyon Member as geologically and hydrologically homogeneous, and the former Presiding Officer's acceptance of that treatment as valid for the Section 8 mine, cannot be accepted given the overwhelming geological evidence of heterogeneity of the Westwater Canyon Member at the level of small scale-channels, which is the level at which ISL mining and its hydrological impacts would take place. In my professional opinion, I believe that HRI erred in so modeling groundwater flow in the Westwater Canyon Member, and that Mr. Wallace's inclusion of small-scale channels in his groundwater modeling is conceptually valid and entirely realistic in light of the evidence of the heterogeneity of the Westwater Canyon Member.

## Summary of Conclusions

52. My studies of two outcrop analogues, my re-evaluation of the subsurface data presented in the Lichnovsky testimony, and my personal knowledge and a review of the literature on Jurassic rocks in west-central New Mexico lead me to conclude:

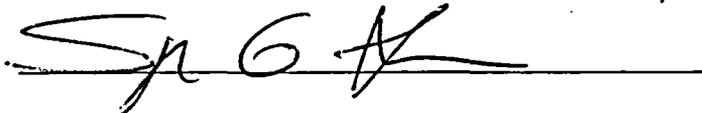
- a. At HRI's proposed Section 17, Unit 1 and Crownpoint mines, there is no aquitard (confinement of groundwater) immediately below the Westwater Canyon Member, the rock unit to be mined;
- b. At HRI's proposed Section 17 mine site near Church Rock, there is no aquitard (confinement of groundwater) immediately above the Westwater Canyon Member, the rock unit to be mined;
- c. At HRI's proposed ISL mines near Crownpoint, there may be no aquitard (confinement of ground water) immediately above the Westwater Canyon Member, the rock unit to be mined;
- d. At HRI's proposed Section 17, Unit 1 and Church Rock ISL mine sites, there is insufficient confinement of groundwater such that it is highly likely that the mining will lead to impairment of groundwater quality in aquifers stratigraphically below, above and lateral to the mining interval;
- e. The FEIS reflects the NRC Staff's own confusion about whether the Recapture Member exists below the Westwater at the three mining sites, and this confusion results in the Staff concluding that there is a sufficiently confining layer below the solution mining horizon at all three sites such

- g. Such heterogeneity will accelerate groundwater flow, inhibiting containment of lixiviant. HRI should have modeled groundwater flow in the subsurface of the mining sites as heterogeneous, not as homogenous.

53. This concludes my testimony.

Pursuant 28 U.S.C. §1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 25 day of February 2005.

A handwritten signature in black ink, appearing to read "Spencer G. Lucas", is written over a solid horizontal line.

Spencer G. Lucas, Ph.D.

**ADDENDUM 1: CAPTIONS FOR FIGURES IN EXHIBIT D:**

**FIGURE 1.** Index map showing locations of HRI's proposed mine sites near Springstead and Crownpoint and the outcrop analogues of these subsurface sites.

**FIGURE 2.** Jurassic lithostratigraphy of the two outcrop analogues.

**FIGURE 3.** Selected Jurassic outcrops at Outcrop Analogue A.

**FIGURE 4.** Selected Jurassic outcrops at Outcrop Analogue B.

**FIGURE 5.** Cross section of Jurassic rocks in west-central New Mexico showing Recapture Member as dominated by sandstone (from Turner-Peterson and Fishman, 1986).

**FIGURE 6.** Description of lithology of Recapture Member on Thoreau quadrangle (outcrop analogue B) by Robertson (1990).

**FIGURE 7.** Identification of shale baseline in geophysical log 8-02.8/17.

**FIGURE 8.** Section of Dakota Sandstone on Westwater Canyon Member at outcrop analogue A (from Owen and Owen, 2003).

**FIGURE 9.** Lithofacies map of Brushy Basin Member (from Turner-Peterson and Fishman, 1986).

**FIGURE 10.** Stratigraphic column at Northeast Church Rock Mine Site (from "Northeast Church Rock Mine Site Assessment," July 2003).

**FIGURE 11.** Stratigraphic column of the Unit 1 and Crownpoint Sites, FEIS Figure 3.5 (at 3-14).

**FIGURE 12.** Reproduction of Figure 18 from Cowan (1991 at 80) showing the large-scale regional architecture of the Westwater Canyon fluvial system.

**FIGURE 13.** Reproduction of a map of the channelized ore zones at HRI's Section 8 ISL mine site from the Section 8 RAP.

# EXHIBIT A

**SPENCER G. LUCAS**  
**QUALIFICATIONS SUMMARY**

I am a paleontologist and stratigrapher who specializes in the study of late Paleozoic, Mesozoic and early Cenozoic vertebrate fossils and continental deposits, particularly in the American Southwest. I have extensive field experience in the western United States as well as in northern Mexico, Costa Rica, Jamaica, Kazakhstan, Soviet Georgia and the People's Republic of China. I have published more than 800 scientific articles and co-edited 14 books. I have authored 3 books. I have 12 years of museum experience and 17 years of teaching experience at the university level.

**EDUCATION**

Ph.D. (1984) Yale University (Geology)  
M.S. (1979) Yale University  
B.A. (1976) University of New Mexico

**WORK EXPERIENCE**

1988-present Curator of Paleontology & Geology, New Mexico Museum of  
Natural History and Science  
1983-1988 Curator of Geology and Adjunct Professor of  
Geology, University of New Mexico  
1982-1983 Environmental Geologist, Esca-Tech Corporation,  
Albuquerque, New Mexico  
1976-1982 Graduate teaching assistantships, research assistantships,  
curatorial assistantships, University of New Mexico and Yale  
University

**PROFESSIONAL AFFILIATIONS**

Paleontological Society, Society of Vertebrate Paleontology, New Mexico Geological Society  
(honorary member), New Mexico Academy of Science (life member)

**EXHIBIT B**

## Publications on Jurassic Geology

Spencer G. Lucas

1984

Upper Triassic-Upper Jurassic stratigraphy, fossil vertebrates and depositional environments, Bull Canyon, Guadalupe County, east-central New Mexico. Geological Society of America, Abstracts with Programs 16:245 (S.G. Lucas, K.K. Kietzke, J.C. Sobus, G. Weadock, N.J. Mateer and A.P. Hunt). [abstract]

Middle Jurassic stratigraphy and fossil fishes, Bull Canyon, Guadalupe County, east-central New Mexico. New Mexico Geology 6:84 (K.K. Kietzke and S.G. Lucas). [abstract]

1985

Dinosaurs from the Upper Jurassic Morrison Formation in New Mexico. New Mexico Journal of Science 25:1-12 (S.G. Lucas and A.P. Hunt).

The Jurassic System in east-central New Mexico; in Lucas, S.G. and Zidek, J., eds., Santa Rosa-Tucumcari region [New Mexico Geological Society, Guidebook, 36th Field Conference], Socorro, New Mexico Geological Society, pp. 213-242 (S.G. Lucas, K.K. Kietzke and A.P. Hunt).

Jurassic stratigraphy and depositional environments in east-central New Mexico. New Mexico Geology 8:22 (A.P. Hunt, S.G. Lucas and K.K. Kietzke). [abstract]

1986

Todilto Formation: a Jurassic salina and its petroleum potential in east-central New Mexico. American Association of Petroleum Geologists Bulletin 70:346 (S.G. Lucas and K.K. Kietzke). [abstract]

Stratigraphy and petroleum potential of the Jurassic Todilto Formation in northeastern New Mexico; in Ahlen, J.L., Hanson, M.E. and Zidek, J., eds., Southwest section of AAPG transactions and guidebook of 1986 convention Ruidoso, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources, pp. 121-127 (S.G. Lucas and K.K. Kietzke).

Fossil fishes and age of uranium mineralization in the Middle Jurassic Todilto Formation of northern New Mexico. *New Mexico Geology* 8:67. [abstract]

Triassic-Jurassic vertebrate biochronology of New Mexico. Fourth North American Paleontological Convention, Abstracts with Programs: 29 (S.G. Lucas and A.P. Hunt). [abstract]

1987

Type section of Exeter Member of Entrada Sandstone, Jurassic of northeastern New Mexico; *in* Lucas, S.G. and Hunt, A.P., eds., *Northeastern New Mexico* [New Mexico Geological Society, Guidebook, 38th Field Conference], Socorro, New Mexico Geological Society, pp. 17–18 (S.G. Lucas, A.P. Hunt and S.N. Hayden).

Stromatolites of the Morrison Formation (Upper Jurassic), Union County, New Mexico: a preliminary report; *in* Lucas, S.G. and Hunt, A.P., eds., *Northeastern New Mexico* [New Mexico Geological Society, Guidebook, 38th Field Conference], Socorro, New Mexico Geological Society, pp. 153–159 (K.R. Neuhauser, S.G. Lucas, J.S. de Albuquerque, R.J. Loudon, S.N. Hayden, K.K. Kietzke, W. Oakes and D. Des Marais).

1988

Todilto as a formation, not a member of the Wanakah Formation, Middle Jurassic of northern New Mexico. *New Mexico Geology* 10:40. [abstract]

1989

The Jurassic section in the Hagan basin, Sandoval County, New Mexico; *in* Lorenz, J.C. and Lucas, S.G., eds., *Energy frontiers in the Rockies*. Albuquerque, Albuquerque Geological Society, pp. 3–5 (C. Pigman and S.G. Lucas).

Jurassic-Cretaceous boundary in west-central New Mexico; *in* Anderson, O.J., Lucas, S.G., Love, D.W. and Cather, S.M., eds., *Southeastern Colorado Plateau* [New Mexico Geological Society, Guidebook, 40th Field Conference], Socorro, New Mexico Geological Society, pp. 6–7.

1990

Jurassic dinosaur footprints from New Mexico; *in* Bauer, P.W., Lucas, S.G., Mawer, C.K. and McIntosh, W.C., eds., Tectonic development of the southern Sangre de Cristo Mountains, New Mexico [New Mexico Geological Society, Guidebook, 41st Field Conference], Socorro, New Mexico Geological Society, pp. 319–321 (S.G. Lucas, A.P. Hunt and P. Huber).

The status of “Jurassic” metoposaurs in the American Southwest. Stegocephalian Newsletter, no. 1, p. 16–17 (A.P. Hunt and S.G. Lucas).

Triassic-Jurassic stratigraphy, Palo Duro Canyon, Sevilleta Grant, Socorro County, New Mexico: *New Mexico Geology*, v. 12, p. 65, 75 (S.N. Hayden, S.G. Lucas, A.P. Hunt and W.C. Beck). [abstract]

Paleomagnetism and rock magnetism of large sandstone pipes in the Beclabito Member of the Wanakah Formation (Formerly Summerville Formation, Middle Jurassic) near Mesita, central New Mexico: *EOS, Transactions, American Geophysical Union*, v. 71, p. 1291 (J.W. Geissman, S. Harlan and S.G. Lucas). [abstract]  
1992

New Mexico’s Jurassic dinosaurs: Timetracks [New Mexico Museum of Natural History], v. 12(2):12–13.

Nonmarine Jurassic-Cretaceous boundary in western North America; *in* Mateer, N.J. and Chen, P.J., eds., *Aspects of Nonmarine Cretaceous Geology*: Beijing, China Ocean Press, p. 15–30 (N.J. Mateer, S.G. Lucas and A.P. Hunt).

The Middle Jurassic Summerville Formation, northern New Mexico: *New Mexico Geology*, v. 14, p. 79-92 (O. J. Anderson and S. G. Lucas).

The Triassic-Jurassic boundary section in the Sierra del Alamo, northwestern Sonora: III Simposio de la Geologia de Sonora y Areas Adyacentes Libro de Resumenes, p. 66-68.

Middle Jurassic depositional setting, western Laurasia (southwestern U. S.): Carboniferous to Jurassic Pangea Programs and Abstracts, p. 6 (O. J. Anderson and S. G. Lucas). [abstract]

Magnetostratigraphy and paleomagnetic poles from Late Triassic-earliest Jurassic strata of the Newark basin: discussion: *Geological Society of America Bulletin*, v. 103, p. 1648-1662 (S. G. Lucas, M. B. Steiner, P. Huber and A. P. Hunt).

Vertebrate biochronology of the Jurassic-Cretaceous boundary, North American Western Interior: *Modern Geology*, v. 18, p. 371-390 [Reprinted in Sarjeant, W. A. S., ed., 1995, *Vertebrate fossils and the evolution of scientific concepts*: Gordon and Breach Publishers, p. 381-400].

1993

Jurassic vertebrates of New Mexico; in Lucas, S. G. and Zidek, J., eds., *Vertebrate paleontology in New Mexico*: New Mexico Museum of Natural History and Science, Bulletin 2, p. 71-75 (A. P. Hunt and S. G. Lucas).

The Middle Jurassic Summerville Formation, northern New Mexico - a rebuttal of Condon, 1993: *New Mexico Geology*, v. 15, p. 66-70 (S. G. Lucas and O. J. Anderson).

Middle-Upper Jurassic stratigraphy and sedimentation on the Colorado Plateau: *New Mexico Geology*, v. 15, p. 72 (S. G. Lucas and O. J. Anderson). [abstract]

Upper Triassic-Lower Jurassic Barranca Group of Sonora, Mexico: depositional setting, age constraints and stratigraphic subdivision: *Geological Society of America, Abstracts with Programs*, v. 26, no. 2, p. 68 (S. G. Lucas and J. E. Marzolf). [abstract]

1994

Middle Jurassic stratigraphy, sedimentation and paleogeography in the southern Colorado Plateau and southern High Plains; in Caputo, M. V., Peterson, J. A. and Franczyk, K. J., eds., *Mesozoic systems of the Rocky Mountain region, USA*: Denver: Rocky Mountain Section, Society for Sedimentary Geology, p. 299-314 (O. J. Anderson and S. G. Lucas).

Correlation and age of the Upper Jurassic Morrison Formation from magnetostratigraphic analysis; in Caputo, M. V., Peterson, J. A. and Franczyk, K. J., eds., *Mesozoic systems of the Rocky Mountain region, USA*: Denver: Rocky Mountain Section, Society for Sedimentary Geology, p. 315-330 (M. B. Steiner, S. G. Lucas and E. M. Shoemaker).

Middle Jurassic stratigraphy, sedimentation and paleogeography in the southwestern United States; *Canadian Society of Petroleum Geologists, Memoir 17*, p. 255-264 (O. J. Anderson and S. G. Lucas).

Ostracoda and Gastropoda from the Kayenta Formation (Lower Jurassic) of Arizona, U.S.A.: *Journal of the Arizona-Nevada academy of Science*, v. 28, p. 23-32 (K. K. Kietzke and S. G. Lucas).

1995

The Jurassic section at Romeroville, San Miguel County, New Mexico; in Bauer, P. W., Kues, B. S., Dunbar, N. W., Karlström, K. E. and Harrison, B., eds., *Geology of the Santa Fe region* [New Mexico Geological Society, Guidebook, 46th Field Conference]:

Socorro, New Mexico Geological Society, p. 51-53 (S. G. Lucas, O. J. Anderson and M. B. Steiner).

Jurassic stratigraphy in the Hagan basin, north-central New Mexico; in Bauer, P. W., Kues, B. S., Dunbar, N. W., Karlstrom, K. E. and Harrison, B., eds., *Geology of the Santa Fe region* [New Mexico Geological Society, Guidebook, 46th Field Conference]: Socorro, New Mexico Geological Society, p. 247-255 (S. G. Lucas, O. J. Anderson and C. Pigman).

Base of the Morrison Formation, Jurassic, of northwestern New Mexico and adjacent areas: *New Mexico Geology*, v. 17, p. 44-53 (O. J. Anderson and S. G. Lucas).

1996

Dinosaur footprints from the Jurassic Summerville Formation, northern New Mexico: *New Mexico Geology*, v. 18, p. 56 (S. G. Lucas and J. W. Estep). [abstract]

Sinemurian (Early Jurassic) ammonites from the Antimonio Formation, Sonora, Mexico: *Geological Society of America, Abstracts with Programs*, v. 28, no. 5, p. 116 (D. G. Taylor, C. Gonzalez-Leon and S. G. Lucas). [abstract]

Stratigraphy and depositional environments of Middle and Upper Jurassic rocks, southeastern San Juan Basin, New Mexico; in Goff, F., Kues, B. S., Rogers, M. A., McFadden, L. D. and Gardner, J. N., eds., *The Jemez Mountains Region* [New Mexico Geological Society, Forty-Seventh Annual Field Conference Guidebook]: New Mexico Geological Society, Socorro, p. 205-210 (O. J. Anderson and S. G. Lucas).

Cordilleran Triassic-Jurassic transition: The Dinosaur Canyon sequence: *Geological Society of America Abstracts with Programs*, v. 28, no. 7, p. 308 (J. E. Marzolf, S. G. Lucas, N. J. Silberling and J. I. Satterfield). [abstract]

The Triassic-Jurassic transition on the Colorado Plateau: Is J-0 a Triassic unconformity?: *Geological Society of America Abstracts with Programs*, v. 28, no. 7, p. 308 (S. G. Lucas, O. J. Anderson, J. E. Marzolf and M. Morales). [abstract]

Paleoclimatic patterns regionally expressed in Bluff Sandstone (Middle to Late?Jurassic): *Geological Society of America Abstracts with Programs*, v. 28, no. 7, p. 308 (O. J. Anderson and S. G. Lucas). [abstract]

Vertebrate biochronology of the Jurassic of China; in Morales, M., ed., *The continental Jurassic: Museum of Northern Arizona Bulletin* 60, p. 23-33.

The thyreophoran dinosaur *Scelidosaurus* from the Lower Jurassic Lufeng Formation, Yunnan, China; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 81-85.

Jurassic fossil vertebrates from New Mexico; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 235-241 (S. G. Lucas, T. E. Williamson, J. W. Estep, A. P. Hunt and O. J. Anderson).

Vertebrate track assemblages from the Jurassic Summerville Formation and correlative deposits; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 249-254 (M. G. Lockley, A. P. Hunt and S. G. Lucas).

Unionid bivalves from the Upper Jurassic Morrison Formation, east-central New Mexico; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 325-327.

Lower Mesozoic sequences of the Colorado Plateau; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 437-438 (J. E. Marzolf and S. G. Lucas).

The base of the Morrison Formation (Upper Jurassic) of northwestern New Mexico and adjacent areas; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 443-456 (O. J. Anderson and S. G. Lucas).

The Middle Jurassic Todilto salina basin, American Southwest; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 479-482 (S. G. Lucas and O. J. Anderson).

Correlation and tectonic significance of Lower Jurassic conglomerates in Sonora, Mexico; in Morales, M., ed., The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 497-501.

Synopsis of the Entrada Sandstone; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 59-63 (O. J. Anderson and S. G. Lucas).

Synopsis of the Bluff Sandstone; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 65-71 (O. J. Anderson and S. G. Lucas).

Synopsis of the Summerville Formation; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 73-77 (O. J. Anderson and S. G. Lucas).

Synopsis of the Morrison Formation; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 79-86 (O. J. Anderson and S. G. Lucas).

Road log from Page to junction of Highways 98 and 160 near Cow Springs, Arizona: 62.6 miles; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 92-94 (S. G. Lucas and O. J. Anderson).

Road log from junction of Highways 98 and 160 near Cow Springs to Kayenta, Arizona: 32.1 miles; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 94-95 (S. G. Lucas and O. J. Anderson).

Road log from Kayenta to Baby Rocks, Arizona; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 96 (S. G. Lucas and O. J. Anderson).

Road log from the junction of highways 98 and 160 near Cow Springs to junction of Highways 89 and 160 west of Tuba City, Arizona: 38.7 miles; in Morales, M., ed., Guidebook for the geological excursion of the continental Jurassic symposium: Flagstaff, Museum of Northern Arizona, p. 96-99 (S. G. Lucas, O. J. Anderson, P. R. Luttrell and M. Morales).

New Mexico's ancient Lake Todilto and its fossils: Timetracks [New Mexico Museum of Natural History Foundation], v. 17, no. 4, p. 4-5

1997

Deposition of the Upper Jurassic Brushy Basin Member of the Morrison Formation, western United States: Geological Society of America Abstracts with Programs, v. 29, no. 2, p. 1 (O. J. Anderson and S. G. Lucas). [abstract]

Triassic-Jurassic stratigraphy, sedimentation and paleogeography in Sonora, Mexico: Geological Society of America Abstracts with Programs, v. 29, no. 2, p. 37. [abstract]

The Triassic-Jurassic transition on the Colorado Plateau: regional considerations: Geological Society of America Abstracts with Programs, v. 29, no. 2, p. 38 (J. E. Marzolf, S. G. Lucas and J. I. Satterfield). [abstract]

The Jurassic San Rafael Group, Four Corners region; in Anderson, O. J., Kues, B. S. and Lucas, S. G., eds., Mesozoic Geology and Paleontology of the Colorado Plateau [New Mexico Geological Society Guidebook 48]: Socorro, New Mexico Geological Society, pp. 115-132 (S. G. Lucas and O. J. Anderson).

The Upper Jurassic Morrison Formation in the Four Corners region; in Anderson, O. J., Kues, B. S. and Lucas, S. G., eds., Mesozoic Geology and Paleontology of the Colorado Plateau [New Mexico Geological Society Guidebook 48]: Socorro, New Mexico Geological Society, pp.139-155 (O. J. Anderson and S. G. Lucas).

An autochthonous Jurassic forearc basin in NW Sonora, Mexico: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A235-A236 (R. S. Molina-Garza, J. W. Geissman and S. G. Lucas). [abstract]

Phytosaur from the Wingate Sandstone in southeastern Utah and the Triassic-Jurassic boundary on the Colorado Plateau; in Anderson, B., Boaz, D. and McCord, R. D., eds., Southwest paleontological symposium proceedings volume 1: Mesa, Mesa Southwest Museum, p. 49-59 (S. G. Lucas, A. B. Heckert, O. J. Anderson and J. W. Estep).

Theropod dinosaur eggshell from the Upper Jurassic of New Mexico; in Lucas, S. G., Estep, J. W., Williamson, T. E. and Morgan, G. S., eds., New Mexico's Fossil Record 1: New Mexico Museum of Natural History and Science Bulletin 11, pp. 41-43 (E. S. Bray and S. G. Lucas).

Deposition of the Upper Jurassic Brushy Basin Member of the Morrison Formation, western United States: Geological Society of America Abstracts with Programs, v. 29, no. 2, p. 1 (O. J. Anderson and S. G. Lucas). [abstract]

1998

Jurassic sauropod dinosaur from the Republic of Georgia: Journal of Vertebrate Paleontology, v. 18, p. 233-236 (L. K. Gabunia, G. Mchedlidze, V. M. Chkikhvadze and S. G. Lucas).

The "type" Wingate Sandstone (Upper Triassic-Lower Jurassic) and the homotaxial Entrada Sandstone (Middle Jurassic): Resolving stratigraphic problems on the southern Colorado Plateau: *New Mexico Geology*, v. 20, p. 54 (A. B. Heckert and S. G. Lucas). [abstract]

Stratigraphy of the Jurassic Entrada Sandstone in New Mexico: *New Mexico Geology*, v. 20, p. 54-55 (S. G. Luca, A. B. Heckert and O. J. Anderson). [abstract]

Redefinition of Morrison Formation (Upper Jurassic) and related San Rafael Group strata, southwestern U. S.: *Modern Geology*, v. 22, p. 39-69 (O. J. Anderson and S. G. Lucas).

A new and unusual sphenosuchian (Archosauria: Crocodylomorpha) from the Lower Jurassic Lufeng Formation, People's Republic of China: *Journal of Vertebrate Paleontology*, v. 18, supplement to no. 3, p. 49A (J. D. Harris, S. G. Lucas, J. W. Estep and J. Li). [abstract]

Jurassic stratigraphy and correlation in New Mexico: *New Mexico Geology*, v. 20, p. 97-104 (S. G. Lucas and O. J. Anderson).

1999

Geology and taphonomy of the Peterson site, New Mexico's most extensive Late Jurassic dinosaur quarry: *New Mexico Geology*, v. 21, p. 43-44 (R. Peterson, R. Peterson, N. V. D'Andrea, S. G. Lucas and A. B. Heckert). [abstract]

Jurassic stratigraphy in the Tijeras syncline, Bernalillo County, New Mexico: *New Mexico Geology*, v. 21, p. 47-48 (S. G. Lucas, J. W. Estep and O. J. Anderson). [abstract]

Early Jurassic stratigraphy and ammonites at Cerro Pozos de Serna, Sonora, Mexico, and their tectonic significance: *Neues Jahrbuch für Geologie und Paläontologie Monatshefte*, v. 1999, p. 357-371 (S. G. Lucas, J. W. Estep and R. S. Molina-Garza).

Middle and Upper Jurassic rocks at Cedar Crest, New Mexico; in Pazzaglia, F. J., Lucas, S. G. and Austin, G. S., eds., *Albuquerque geology [New Mexico Geological Society Guidebook, 50<sup>th</sup> Field Conference]*: Socorro, New Mexico Geological Society, p. 36-37 (O. J. Anderson, S. G. Lucas and J. W. Estep).

Correlation of Jurassic strata from the Colorado Plateau to the High Plains, across the Rio Grande rift, north-central New Mexico; in Pazzaglia, F. J., Lucas, S. G. and Austin, G. S., eds., *Albuquerque geology [New Mexico Geological Society Guidebook, 50<sup>th</sup> Field Conference]*: Socorro, New Mexico Geological Society, p. 317-326 (S. G. Lucas, J. W. Estep and O. J. Anderson).

Geological context and preliminary taphonomic analysis of the Peterson site, a Late Jurassic dinosaur quarry in New Mexico: *Journal of Vertebrate Paleontology*, v. 19,

supplement to no. 3, p. 68A (R. Peterson, R. Peterson, N. V. D'Andrea, S. G. Lucas and A. B. Heckert). [abstract]

Paleomagnetism and correlation of Triassic-Jurassic strata of the Colorado Plateau: Geological Society of America, Abstracts with Programs, v. 31, no. 7, p. A-234 (R. S. Molina-Garza, J. W. Geissman and S. G. Lucas). [abstract]

Triassic-Jurassic boundary in the Sierra del Alamo Muerto, Sonora, Mexico: *Albertiana*, no. 23, p. 36-41. (S. G. Lucas and J. W. Estep)

Permian, Triassic, and Jurassic stratigraphy, biostratigraphy, and sequence stratigraphy in the Sierra del Alamo Muerto, Sonora, Mexico; in Bartolini, C., Wilson, J. L. and Lawton, T. F., eds., *Mesozoic sedimentary history of north-central Mexico*: Geological Society of America, Special Paper 340, p. 271-286. (S. G. Lucas and J. W. Estep)

2000

Paleoecological significance of Middle Jurassic insect locality, Todilto Formation, north-central New Mexico; in Lucas, S. G., ed., *New Mexico's fossil record 2: New Mexico Museum of Natural History & Science Bulletin 16*, p. 41-44. (S. G. Lucas, L. F. Rinehart and J. W. Estep)

A new and unusual sphenosuchian (Archosauria: Crocodylomorpha) from the Lower Jurassic Lufeng Formation, People's Republic of China: *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, v. 215, p. 47-68 (J. D. Harris, S. G. Lucas, J. W. Estep and J. Li).

Implications of Jurassic, Cretaceous, and Proterozoic piercing lines for Laramide oblique-slip faulting in New Mexico and rotation of the Colorado Plateau: Discussion: *Geological Society of America Bulletin*, v. 112, p. 789-795 (S. G. Lucas, O. J. Anderson and B. A. Black).

Diplodocid (Dinosauria: Sauropoda) skull and jaw material from the Upper Jurassic Morrison Formation, central New Mexico: *New Mexico Geology*, v. 22, p. 51 (A. B. Heckert, S. G. Lucas, R. E. Peterson, R. E. Peterson and N. V. D'Andrea). [abstract]

The Todilto salina basin, Middle Jurassic of the U. S. Southwest; in Gierlowski-Kordesch, E. H. and Kelts, K. R., eds., *Lake basins through space and time: AAPG Studies in Geology 46*, p. 153-158 (S. G. Lucas and O. J. Anderson).

Jurassic dinosaurs in New Mexico: *New Mexico Museum of Natural History and Science Bulletin 17*, p. 43-45. (S. G. Lucas and A. B. Heckert)

Stratigraphy, taphonomy, and new discoveries from the Upper Jurassic (Morrison Formation: Brushy Basin Member) Peterson quarry, central New Mexico: *New Mexico*

Museum of Natural History and Science Bulletin 17, p. 51-59. (A. B. Heckert, S. G. Lucas, K. E. Zeigler, R. E. Peterson, R. E. Peterson and N. V. "D." D'Andrea)

The gastromyths of "*Seismosaurus*," a Late Jurassic dinosaur from New Mexico: New Mexico Museum of Natural History and Science Bulletin 17, p. 61-67.

Stratigraphy of the Bisbee Group (Jurassic-Cretaceous), Little Hatchet Mountains, New Mexico; in Lawton, T. F., McMillan, N. J., McLemore, V. T., Austin, G. S. and Barker, J. M., eds., Southwest passage: A trip through the Phanerozoic [New Mexico Geological Society 51<sup>st</sup> Field Conference Guidebook]: Socorro, New Mexico Geological Society, p. 175-194. (S. G. Lucas and T. F. Lawton)

Probable protosuchid crocodylomorph from the Early Jurassic Navajo Sandstone of north-central Arizona: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A-14 (L. F. Rinehart, A. B. Heckert, G. Bryant, R. Cushman and S. G. Lucas). [abstract]

Jurassic stratigraphy at Placitas, New Mexico and its regional significance: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. A-458 (O. J. Anderson and S. G. Lucas). [abstract]

2001

Protosuchid crocodylomorphs from the Lower Jurassic Navajo Sandstone of north-central Arizona: Western Association of Vertebrate Paleontologists, Mesa Southwest Museum and Southwest Paleontological Society Meeting Abstracts, p. 23 (L. F. Rinehart, A. B. Heckert, S. G. Lucas, G. Bryant and R. Cushman). [abstract]

Late Jurassic invertebrate fossils from the Little Hatchet Mountains, southwestern New Mexico: New Mexico Geology, v. 23, p. 16-20 (S. G. Lucas, K. E. Zeigler, T. F. Lawton and H. F. Filkorn).

J-5 unconformity: A tectonosequence boundary in the Jurassic Western Interior basin: Geological Society of America, Abstracts with Programs, v. 33, no. 5, p. A22 (S. G. Lucas and A. B. Heckert). [abstract]

Theropod dinosaurs and the Early Jurassic age of the Moenave Formation, Arizona-Utah, USA: Neues Jahrbuch für Geologie und Paläontologie Monatshefte, v. 2001, p. 435-448 (S. G. Lucas and A. B. Heckert).

Jurassic strata in east-central New Mexico and their regional significance; in Lucas, S. G. and Ulmer-Scholle, D. S., eds., Geology of the Llano Estacado: New Mexico Geological Society Guidebook 52, p. 203-212 (S. G. Lucas and L. A. Woodward).

The Middle Jurassic Entrada Sandstone near Gallup, New Mexico: Discussion: The Mountain Geologist, v. 38, p. 225-227 (S. G. Lucas, A. B. Heckert and O. J. Anderson).

Protosuchid crocodylomorphs from the Lower Jurassic Navajo sandstone of north-central Arizona: Mesa Southwest Museum Bulletin 8, p. 25-31 (L. F. Rinehart, A. B. Heckert, G. Bryant, S. G. Lucas and R. Cushman).

2002

Revision of stratigraphy across the Triassic-Jurassic boundary, Four Corners region, southwestern USA: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 138 (, L. H. Tanner, S. G. Lucas, P. K. Reser and M. G. Chapman). [abstract]

Correlation and sequence stratigraphy of Jurassic San Rafael Group, SE Utah: Implications for modelling deposition of wet eolian systems: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 280 (O. J. Anderson and S. G. Lucas). [abstract]

2003

Evolution of Middle-Upper Jurassic depositional systems, southern Western Interior: Geological Society of America, Abstracts with Programs, v. 35, no. 5, p. 35. (S. G. Lucas, A. B. Heckert, K. E. Zeigler and A. P. Hunt) [abstract]

No mass extinction at the Triassic-Jurassic boundary: Geological Association of Canada, Program with Abstracts, v. 28, p. 103. (S. G. Lucas, L. H. Tanner and M. G. Chapman) [abstract]

Paleomagnetism and magnetostratigraphy of the lower Glen Canyon and upper Chinle groups, Jurassic-Triassic of northern Arizona and northeast Utah: Journal of Geophysical Research, v. 108, no. B4, 2181, p. 1-24; doi: 10.1029/2002JB001909, 2003 (R. S. Molina-Garza, J. W. Geissman and S. G. Lucas).

No dextral offset of Jurassic strata across the Defiance monocline; in Lucas, S. G., Semken, S. C., Berglof, W. R. and Ulmer-Scholle, D. S., eds., Geology of the Zuni Plateau: Socorro, New Mexico Geological Society Guidebook 54, p. 7-8.

Lectostratotype section of the Jurassic Todilto Formation, western New Mexico; in Lucas, S. G., Semken, S. C., Berglof, W. R. and Ulmer-Scholle, D. S., eds., Geology of the Zuni Plateau: Socorro, New Mexico Geological Society Guidebook 54, p. 15-16. (S. G. Lucas, A. B. Heckert and W. R. Berglof)

Jurassic stratigraphy in west-central New Mexico; in Lucas, S. G., Semken, S. C., Berglof, W. R. and Ulmer-Scholle, D. S., eds., Geology of the Zuni Plateau: Socorro, New Mexico Geological Society Guidebook 54, p. 289-301. (S. G. Lucas and A. B. Heckert)

An Upper Jurassic theropod dinosaur from the section 19 mine, Morrison Formation, Grants uranium district; in Lucas, S. G., Semken, S. C., Berglof, W. R. and Ulmer-Scholle, D. S., eds., *Geology of the Zuni Plateau: Socorro, New Mexico Geological Society Guidebook 54*, p. 309-314. (A. B. Heckert, J. A. Spielmann, S. G. Lucas, R. Altenberg, R. and D. M. Russell)

Geology and paleontology of the Upper Jurassic (Morrison Formation: Brushy Basin Member) Peterson quarry, central New Mexico; in Lucas, S. G., Semken, S. C., Berglof, W. R. and Ulmer-Scholle, D. S., eds., *Geology of the Zuni Plateau: Socorro, New Mexico Geological Society Guidebook 54*, p. 315-324. (A. B. Heckert, K. E. Zeigler, S. G. Lucas, J. A. Spielmann, P. M. Hester, R. E. Peterson, R. E. Peterson and N. V. D'Andrea).

Jurassic unconformities in the Western Interior: Confusing lithostratigraphy and chronostratigraphy: Geological Society of America, *Abstracts with Programs*, v. 35, no. 6, p. 88. [abstract]

Rethinking the mass extinction at the Triassic-Jurassic boundary: Geological Society of America, *Abstracts with Programs*, v. 35, no. 6, p. 417. (S. G. Lucas, L. H. Tanner and A. B. Heckert) [abstract]

2004

Stratigraphy of the Jurassic San Rafael Group along the Picuris-Pecos fault system, Santa Fe County, New Mexico: *New Mexico Geology*, v. 26, p. 71. (S. G. Lucas and S. M. Cather) [abstract]

Ichnofaunas from the Triassic-Jurassic boundary sequences of the Gateway area, western Colorado: Implications for faunal composition and correlations with other areas: *Ichnos*, v. 11, p. 89-102. (M. G. Lockley, S. G. Lucas, A. P. Hunt and R. Gaston)

The Triassic and Jurassic systems in New Mexico; in Mack, G. H. and Giles, K. A., eds., *The geology of New Mexico: A geologic history: New Mexico Geological Society Special Publication 11*, p. 137-152.

Proposal of the New York Canyon section (Gabbs Valley Range, Nevada, USA) as stratotype of the Triassic-Jurassic boundary: 32<sup>nd</sup> International Geological Congress, *Abstracts*, p. 1138 (J. Guex, D. Taylor, A. Bartolini, V. Atudorei and S. G. Lucas). [abstract]

Vertebrate ichnology at the Triassic-Jurassic boundary in eastern Utah: New evidence from the Wingate Formation: *Journal of Vertebrate Paleontology*, v. 24, supplement to no. 3, p.99A (G. Odier, M. Lockley and S. Lucas). [abstract]

Therapsid burrows in the Lower Jurassic Navajo Sandstone, southeastern Utah:  
Geological Society of America, Abstracts with Programs, v. 36, no. 5, p. 67 (G. P. Odier,  
S. G. Lucas, T. McCormick and C. Egan). [abstract]

**EXHIBIT C**

May 20, 1999

UNITED STATES OF AMERICA  
NUCLEAR REGULATORY COMMISSION  
ATOMIC SAFETY AND LICENSING BOARD PANEL

Before Administrative Judge Peter B. Bloch

<hr/>		)	
In the Matter of		)	
		)	
HYDRO RESOURCES, INC.		)	Docket No. 40-8968-ML
2929 Coors Road Suite 101		)	
Albuquerque, NM 87120		)	ASLBP No. 95-706-01-ML
<hr/>		)	

RESPONSE AFFIDAVIT OF DR. SPENCER G. LUCAS

I, Spencer G. Lucas, being duly sworn, make the following statement in response to Hydro Resources, Inc.'s Reply to April 21, 1999 Memorandum and Order (Questions) (May 11, 1999) and to the Affidavit of Craig S. Bartels ("Bartels Affidavit"), attached thereto, with respect to Questions 2 and 8:

1. My name is Spencer G. Lucas. I obtained a Ph.D. in geology from Yale University in 1984. I am currently the Curator of Paleontology and Geology at the New Mexico Museum of Natural History, a position that I have held since 1988. In addition, I have served as an Adjunct Professor of Geology at the University of New Mexico since 1988.
2. I have extensive knowledge of the geology for which Hydro Resources, Inc. ("HRI") proposes the Crownpoint Uranium Project. The Westwater Canyon Member Aquifer in the Morrison Formation was deposited in Late Jurassic time. I began to conduct field studies of Jurassic strata in New Mexico in 1983. In 1988, this research program expanded to a regional study of Jurassic stratigraphy,



paleontology and sedimentation in the Four Corners states. As a result of my research, I co-led three field conferences of the New Mexico Geological Society (in 1985, 1989 and 1997) in which a major focus was the Jurassic rocks. I have published several dozen articles and abstracts on Jurassic strata in New Mexico, which encompass a major re-interpretation of Middle-Late Jurassic stratigraphy, deposition and paleogeography in the American Southwest. Further details of my professional qualifications are set forth in my curriculum vitae, which is attached as Exhibit A, and in my scientific bibliography, which is attached as Exhibit B.

3. In preparation of this affidavit I reviewed the following materials:

-Intervenors' Amended Written Presentation in Opposition to Hydro Resources, Inc.'s Application for a Materials License with Respect to: Groundwater Protection and Exhibits (January 18, 1999);

-Hydro Resources, Inc.'s Response to Intervenors' Brief in Opposition to Hydro Resources, Inc.'s Application for a Materials License with Respect to Groundwater Issues, Lichnovsky Affidavit (February 19, 1999);

-The Presiding Officer's April 21, 1999 Memorandum and Order (Questions);

-Hydro Resources, Inc.'s Reply to April 21, 1999 Memorandum and Order (Questions) (May 11, 1999) and the attached Affidavit of Craig S. Bartels;

-Campbell, C. V., 1976, Reservoir geometry of a fluvial sheet sandstone: American Association of Petroleum Geologists Bulletin, v. 60, p. 1009-1020;

-Cowan, E. J. 1991. The large-scale architecture of the fluvial Westwater Canyon Member, Morrison Formation (Upper Jurassic), San Juan Basin, New Mexico: SEPM Concepts in Sedimentology and Paleontology 3, p. 80-93;

-Walker, R. G., 1992, Facies, facies models and modern stratigraphic concepts; in Walker, R. G. and James, N. P., eds., Facies models: Geological Association of Canada, St. John's, Newfoundland, p. 1-14.

4. Question 2 of the April 21, 1999 Order asks:

Based on local geology, what assurance is there concerning the likelihood of the existence of shears, fractures, and joints that could transmit appreciable quantities of water above or below the Westwater aquifer? How much greater assurance may reasonably be anticipated prior to commencing ISL operations at Churchrock Section 8? What environmental costs may reasonably be expected to result from foreseeable difficulties at Churchrock Section 8?

Michael G. Wallace responds to HRI's Response to this question in his affidavit.

The following comments are intended to supplement his response.

5. HRI claims (citing the FEIS) that the mine zone in the Westwater is confined by good aquitards, with good overlying clays and underlying shale. HRI Response at 8. Specifically, HRI claims that there is little risk of excursion into the underlying Cow Springs aquifer because of the thickness of the Recapture shale. HRI Response at 10. I concur with the January 11, 1999, testimony of Mr. Wallace that the Recapture Shale is not a confining layer in this region because the Recapture is a fluvial deposit in the southern part of the San Juan Basin. The nomenclature used in this instance is misleading and outdated.
6. The rock section immediately below the Westwater Canyon Member is not shale – it is a mixture of sandstone, siltstone and thin gypsum beds that overlie the gypsum beds of the upper Todilto Formation. These gypsum beds regionally are known to be very ductile and soluble. Thus, they are easily deformed or dissolved, and this produces numerous fractures in the subsurface and at the surface. These fractures are well documented because they are conduits for groundwater flow and also sometimes serve as the loci of uranium mineralization.
7. Mr. Bartels refers to the overlying layers at Church Rock as the Poison Canyon and Dakota formations. Bartels Affidavit at 9. In fact, the Poison Canyon is the

designation of an ore horizon in the Ambrosia Lake/Laguna region of New Mexico. The overlying layers at Church Rock about the Westwater are the Brushy Basin B sand and the Dakota formations. This is a remarkable error, which undermines confidence in HRI's ability to understand the details of geologic conditions in Church Rock.

8. Question 8 of the April 21, 1999 Order asks:

Intervenors Groundwater Exhibit L quotes Cowan (1991), who states that near Church Rock, channelways "15-30 m. thick" occur "which would affect fluid flow." SRIC/ENDAUM will please promptly provide a reference for the citation so that we may discover whether Cowan says anything about the width of these channelways.

9. The citation is correct in that the Cowan study identifies channelways within the channel system which conduct fluid flow along channel boundaries. HRI's attorney criticizes the Cowan study as "mostly a two dimensional study..." that is "based on a very small portion of the Westwater Canyon Member." HRI Response at 41. These criticisms are unfounded. HRI's statement that "Cowan's description of the Westwater Canyon as made up of coalesced sand sheets precludes the existence of confined elongated channels" is also a misreading of the article. HRI Response at 41.

10. Cowan is a state-of-the-art scientific study designed to reconstruct the fluvial architecture of the Westwater Canyon Member of the Morrison Formation in west-central New Mexico. In a sedimentological study such as that of Cowan, an architectural element is defined as a "morphological subdivision of a particular depositional system that emphasizes the three dimensional geometry of the facies

[rock environment] associations” (Walker, 1992, p. 2, 5). In other words, the term architecture is used by sedimentologists to mean the three dimensional geometry of a rock body formed in a particular environment. Indeed, both the text and the illustrations of Cowan’s article (see especially his figure 18, Exhibit C) make it clear that the goal is to reconstruct, in three dimensions, the fluvial system which deposited the Westwater Canyon Member.

11. Therefore, HRI’s statement that Cowan’s article “is mostly a two-dimensional study...” is misleading.
12. Cowan (1991) re-evaluates an important study of Westwater Canyon Member deposition by Campbell (1976), who concluded that deposition took place in channel systems 1.6 to 34 km wide by a braided river system composed of many smaller channels with widths of 30 to 366 m. Cowan argues that the channel systems identified by Campbell are not primary depositional features, but instead are “post-depositional aquifer conduits, or permeability-pathway components” (p. 80). Cowan concludes that Westwater Canyon deposition was in channel belts one to several km wide composed of numerous, smaller channels. Cowan’s article thus well documents the lithologic heterogeneity of the Westwater Canyon Member at the scale of the small channels (which are associated with lenticular bar and overbank deposits) and the continuity of long, nearly linear channel belts. A modern analogy is the depositional development of the Rio Grande and upper-middle reaches of the Mississippi Rivers, as they change course and sediments accumulate, forming sandbars. Therefore, the statement of HRI’s attorney that “Cowan’s description of the Westwater Canyon as made up of coalesced sand

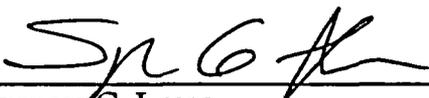
sheets precludes the existence of confined elongated channels” is a misreading of the article.

13. What HRI fails to appreciate is that at a “small scale” (channel widths of tens to hundreds of meters), the Westwater Canyon is a three-dimensionally very complex amalgamation of many coalesced channel, bar and overbank deposits. But, at a “large scale” (widths of hundreds of meters to a few kms) the Westwater Canyon Member consists of long, discrete channel belts, just like those produced by modern braided rivers. Thus, at the small scale the Westwater Canyon is lithologically heterogeneous, consisting of numerous, interlaced ribbon-like sandstone bodies and lenses of conglomerate and mudrock, but only at the large scale can each channel belt be superficially characterized as sandstone, because the majority of the deposit is sandstone.
14. Cowan’s article can be used to conclude there must be at least two levels of permeability/porosity in the Westwater Canyon Member: (1) the small scale (averaging 30 meters (100 feet)) of complex conduits; and (2) large scale conduits that correspond to the channel belts. There must also be a third scale of permeability as well according to Cowan, at the scale of Campbell’s (1976) channel systems, which is up to 34 km in width. With these superimposed levels (scales) of permeability/porosity, small channel effects greatly complicate the understanding of groundwater flow in the larger channels.
15. HRI also attempts to dismiss the significance of Cowan’s study by stating it is “based on a very small portion of the Westwater Canyon Member.” However, Cowan’s study is placed in a basinal context and examines in detail an outcrop

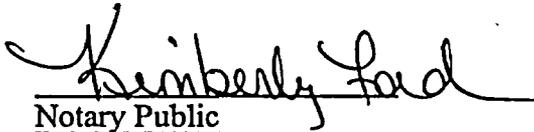
belt characteristic of the Westwater Canyon Member. This is standard sedimentological procedure, and there is no reason to believe that Cowan's conclusions do not apply to the Westwater Canyon throughout its depositional extent. Indeed, Cowan's study area is just east of Gallup near Red Rock State Park, only a few miles west of Church Rock. Any competent geologist would readily extend Cowan's conclusions into the Church Rock area, given the vast scale of the Westwater Canyon Member river system.

AFFIRMATION

I declare on this 20th day of May, 1999, at Albuquerque, New Mexico,  
under penalty of perjury that the foregoing is true and correct to the best of my  
knowledge, and the opinions expressed herein are based on my best professional  
judgment.

  
Spencer G. Lucas

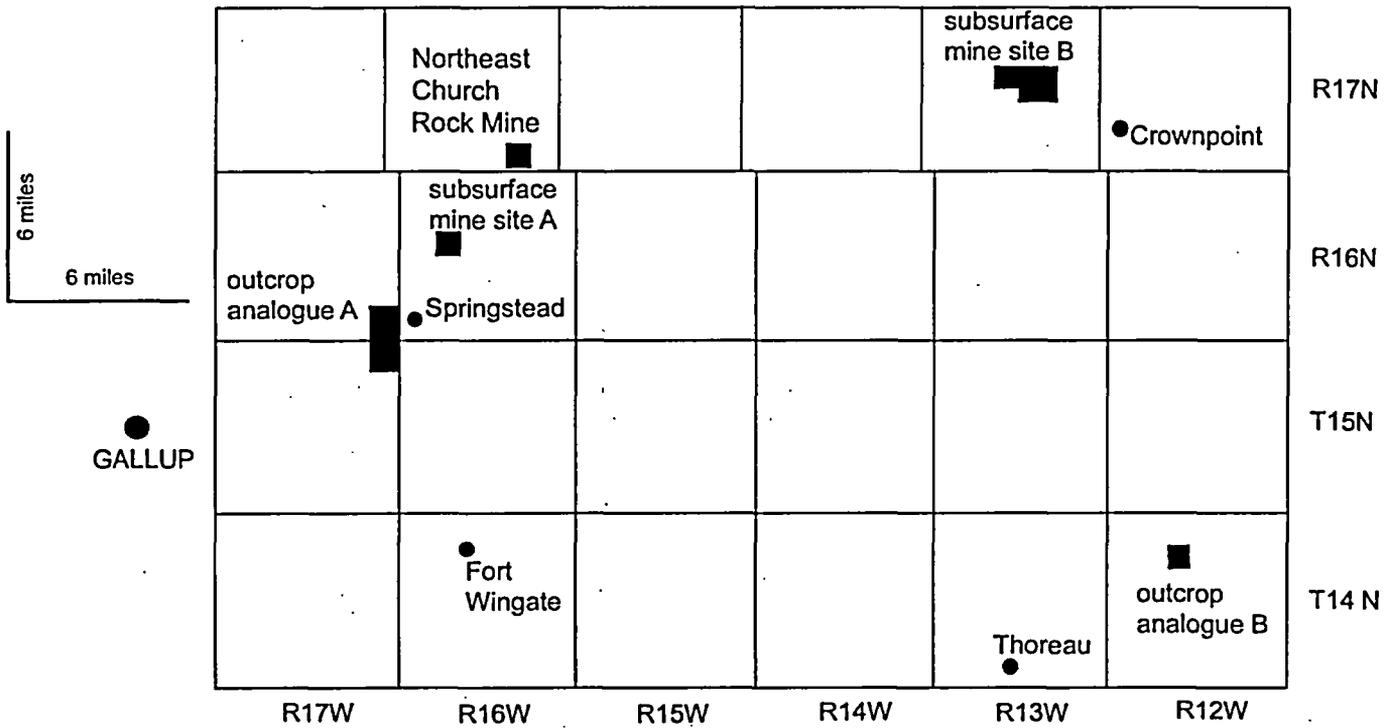
Sworn and subscribed before me, the undersigned, a Notary Public in and for  
the State of New Mexico, on this 20th day of May, 1999.

  
Notary Public

My Commission expires on:

10-22-2002

# EXHIBIT D



subsurface mine site A = Section 17, T16N, R16W  
 subsurface mine site B = Sections 15-16, 21-23, T17N, R13W

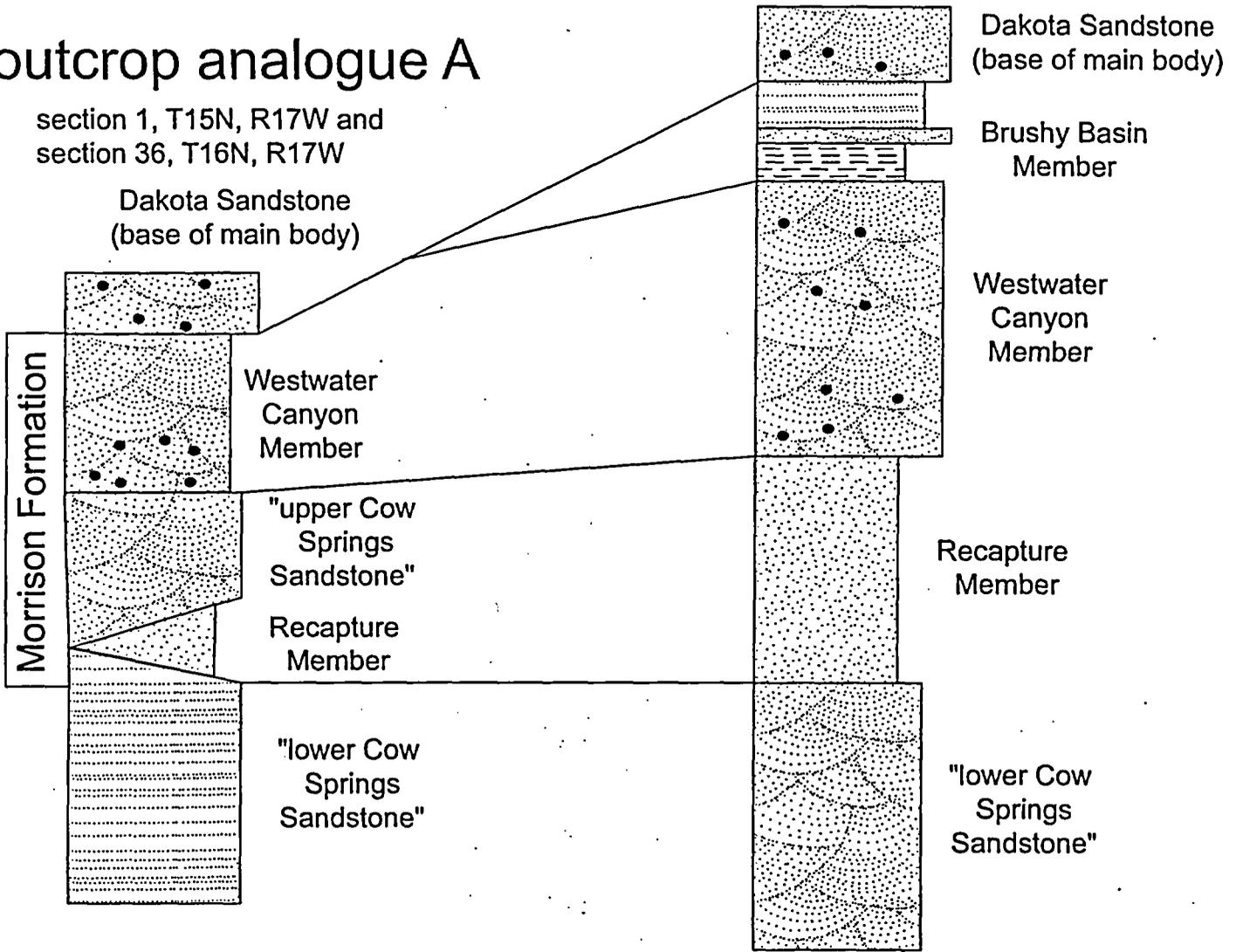
FIGURE 1

# outcrop analogue B

section 8, T14N, R12W

# outcrop analogue A

section 1, T15N, R17W and  
section 36, T16N, R17W



crossbedded sandstone and conglomerate



crossbedded sandstone



flat-bedded sandstone



complexly interbedded sandstone, siltstone and silty claystone



claystone and minor sandstone

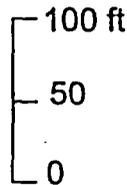
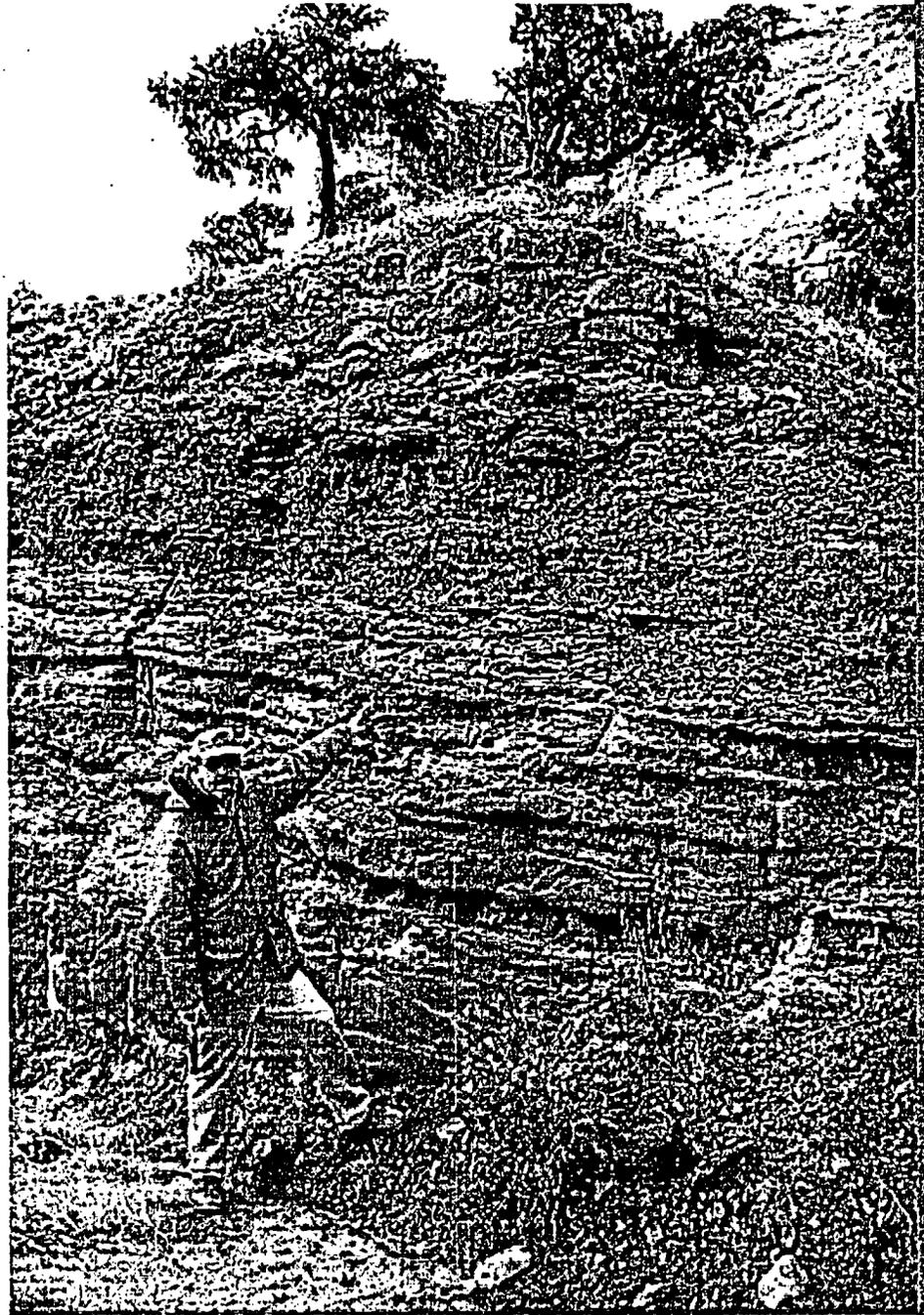


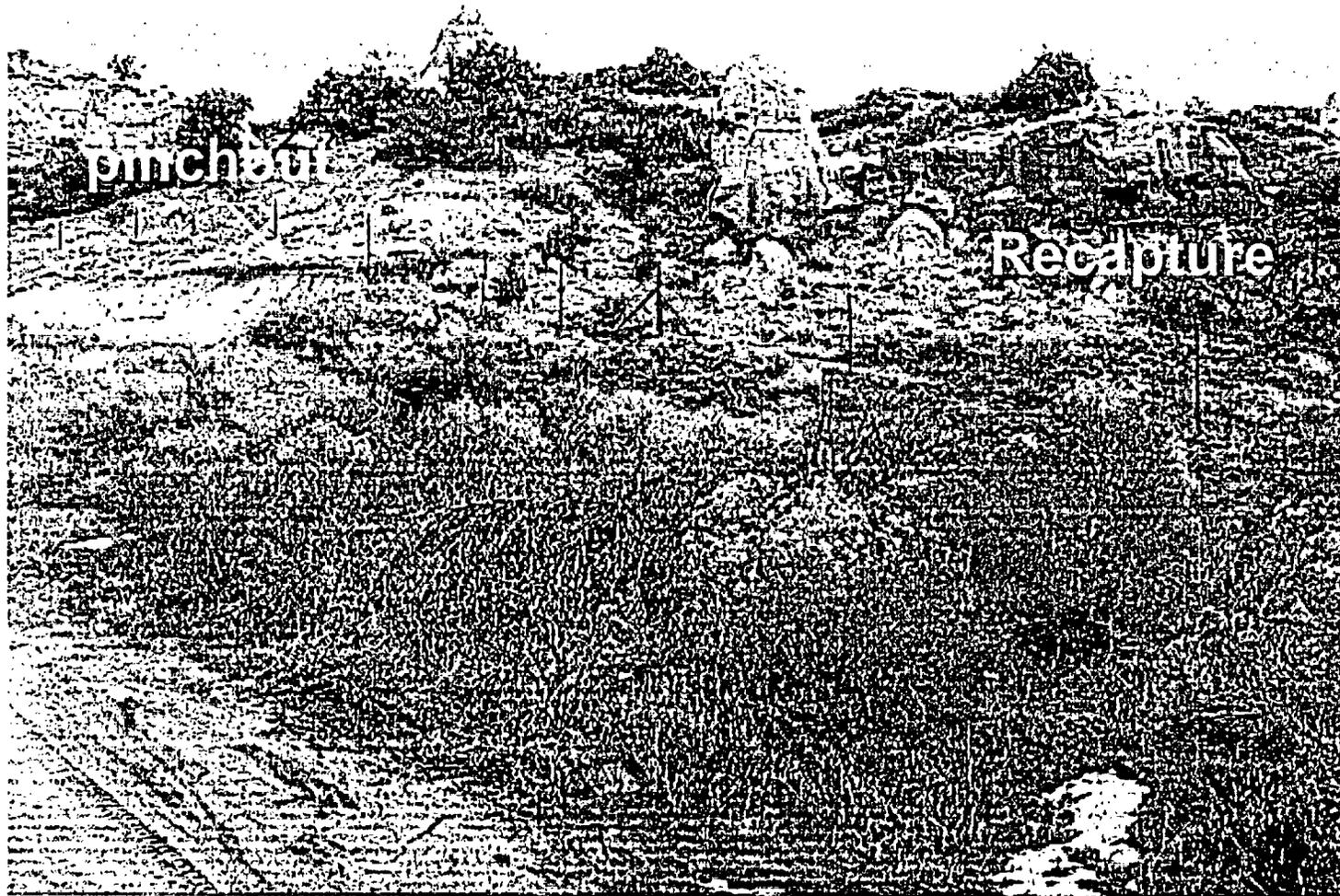
Figure 2

**Figure 3.1,  
Outcrop  
Analogue A**

- ✓ Outcrop of Recapture Member along Rt. 566 in Church Rock, N.M., showing dominance of sandstones

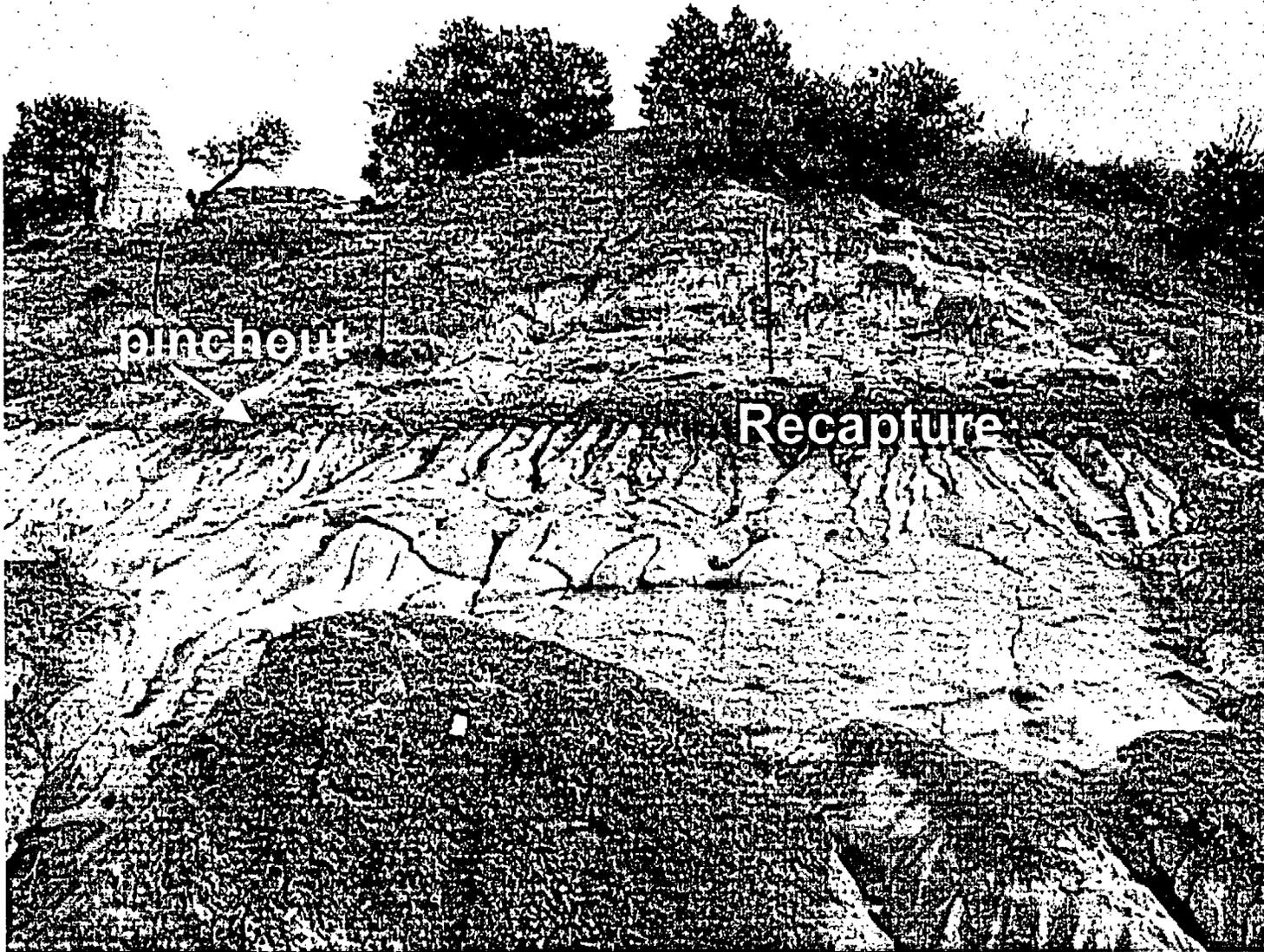


# Figure 3.2, Outcrop Analogue A



Pinchout of red Recapture Member between sandstones of Cow Springs SS

## Figure 3.3, Outcrop Analogue A



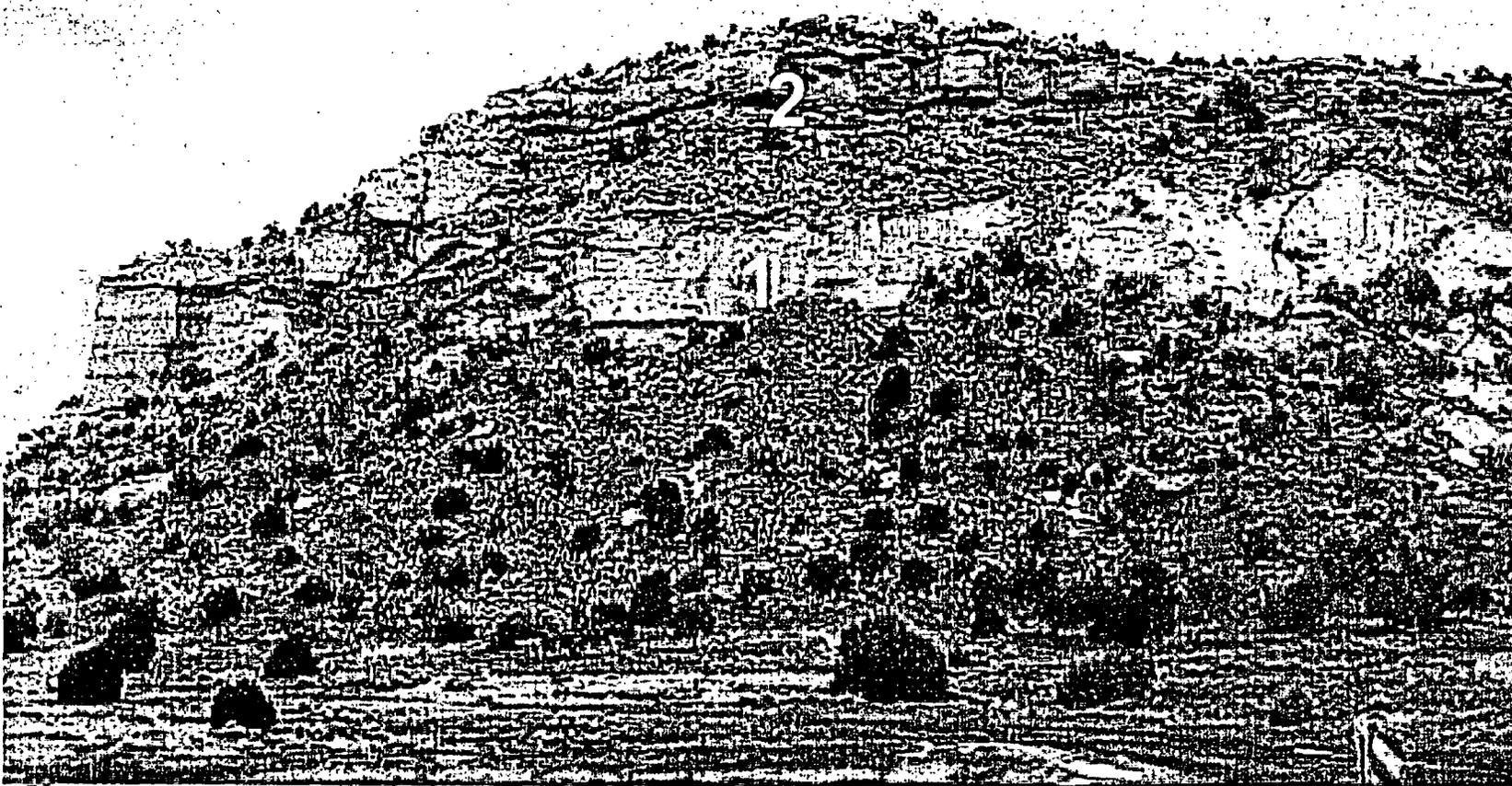
Closeup of pinchout of Recapture Member; red bed is clayey siltstone

## Figure 3.4, Outcrop Analogue A



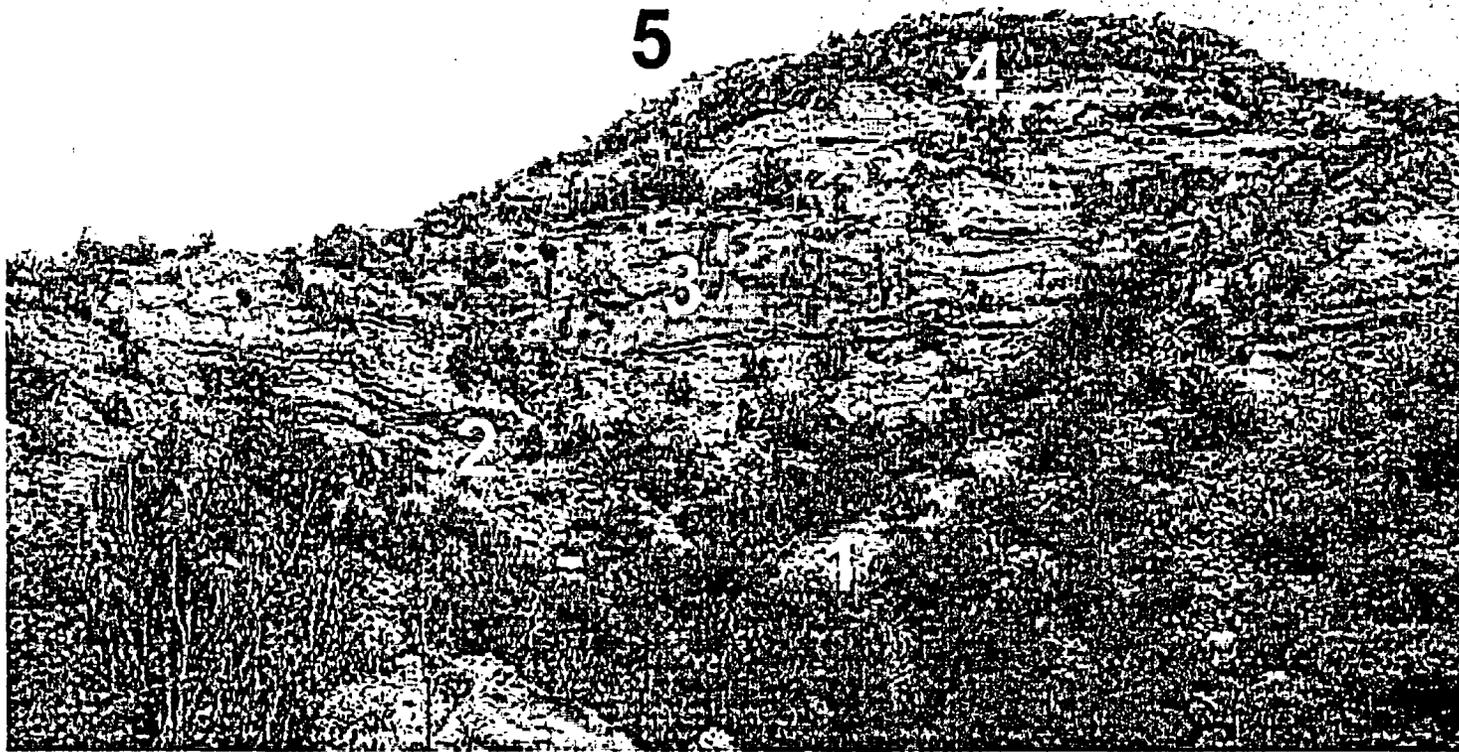
Westwater Canyon Member sandstone (1) resting directly on sandstone at top of Cow Springs Sandstone (0)

## Figure 3.5, Outcrop Analogue A



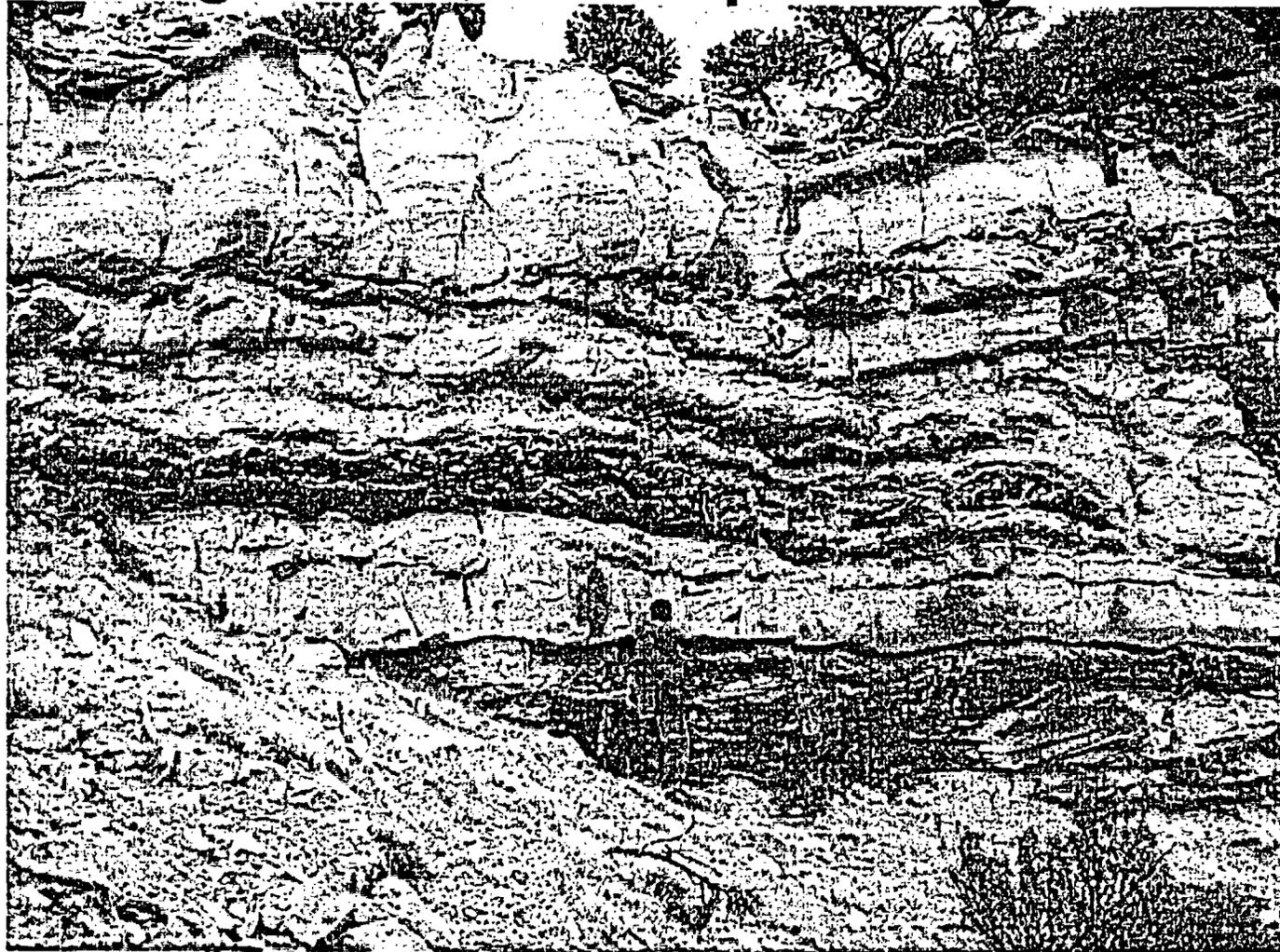
White Rock Mesa, Church Rock Chapter; Dakota Sandstone (2) rests directly on Westwater Canyon Sandstone (1); no Brushy Basin Member present

## Figure 4.1, Outcrop Analogue B



- Overview of Outcrop Analogue A northeast of Thoreau, N.M., showing sandstone-dominated section of Cow Springs (1), Recapture (2), Westwater Canyon (3), Brushy Basin (4) and Dakota (5) stratigraphic units

## Figure 4.2, Outcrop Analogue B



Closeup of Recapture member showing interbedded sandstones (lighter colored beds) and clayey siltstones (red beds)

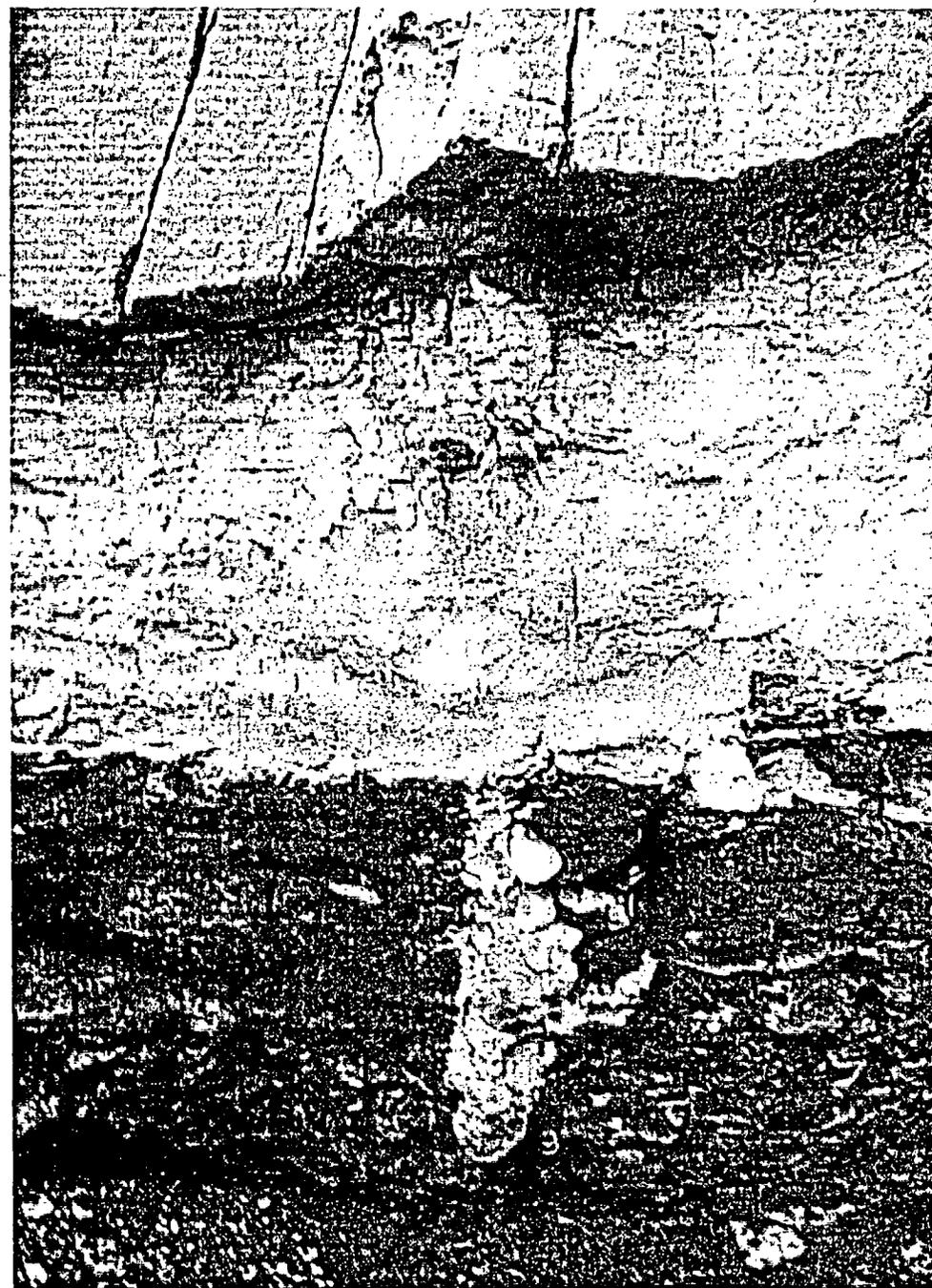
## Figure 4.3, Outcrop Analogue B



Closeup of characteristic crossbedded sandstone bed in Recapture Member

## Figure 4.4, Outcrop Analogue A

✓ Closeup of coarse sandstone (brown layer at top), fine sandstone (middle greenish bed), and clayey siltstone (red bed at bottom). Light-colored structure that crosses axis of lower red bed is either root cast or small-scale, filled fractures



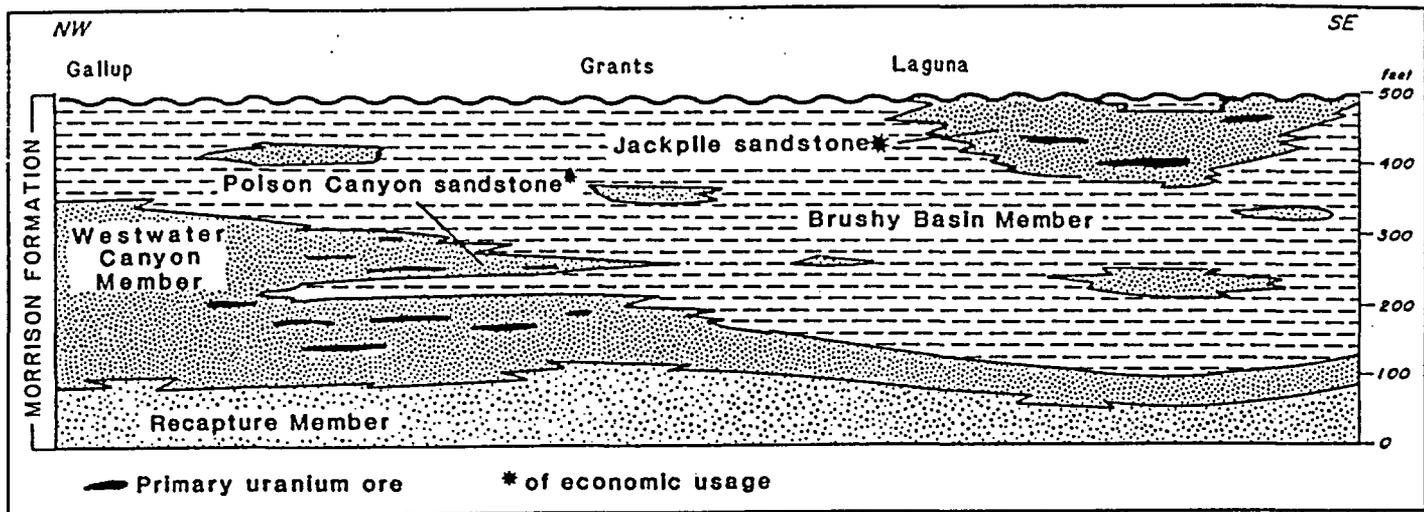


Figure 5: Schematic diagram of the Morrison Formation, southern San Juan basin, showing distribution of ore-bearing sandstones. (Modified slightly from Hilpert, 1963).

FIGURE 5

DEPARTMENT OF THE INTERIOR  
U.S. GEOLOGICAL SURVEYGEOLOGIC MAP OF THE THOREAU QUADRANGLE,  
McKINLEY COUNTY, NEW MEXICO

By Jacques F. Robertson



**Brushy Basin Member**—Pale-olive (10Y6/2) and light-olive-gray (5Y5/2), massive, sandy mudstone; greenish- and reddish- to purplish-gray, thinly bedded and laminated siltstone, claystone, and shale. Largely bentonitic from incorporated altered air-fall and water-laid tuff. Contains lenses of interbedded feldspathic sandstone. Intertongues with underlying Westwater Canyon Member (Jmw). Mainly of fluvial flood-plain and lacustrine origin. Thickness 24–45 m



**Brushy Basin Member**—Light-yellowish-brown, pale-red (5R7/6), and white, fine- to coarse-grained, poorly sorted, friable, trough-crossbedded, feldspathic sandstone, similar to underlying sandstone of Westwater Canyon Member (Jmw). Locally sandstone is conglomeratic, and contains abundant chert pebbles and clay balls, and a scattering of igneous rock types. Sandstone has a detrital and authigenic clay matrix. Authigenic clay consists of clots (or nests) of white kaolin. Only lenses large enough to map are shown. Geometry of sandstone bodies, primary sedimentary structures, and textural characteristics indicate a fluvial-channel origin. Thickness 0–18 m



**Westwater Canyon Member**—Moderate-red (5R6/4) to pale-red (10R6/2) and orange-pink (10R6/4), fine- to coarse-grained, fairly well to poorly sorted, trough-crossbedded, feldspathic sandstone; forms imposing cliffs of stacked channels, generally in two tiers. Contains a few thin lenses of grayish-red (5R4/2) claystone that represent abandoned channel-fill and overbank deposits. Locally includes very coarse sandstone and chert-pebble conglomerate; commonly contains rip-up clay clasts in basal part of scour channels. Mottling common from concentrations of white authigenic kaolin in the matrix. Contains limestone concretions as much as 3 m in diameter that promote picturesque hoodoo forms of weathering. Intertongued with Recapture Member (Jmr). Deposited from extensive braided stream-fan system. Thickness 36–67 m



**Recapture Member**—Upper half consists of interbedded thick beds of fine- to coarse-grained, poorly sorted and friable, moderate-grayish-pink (5R7/2) to white and very pale orange (10YR8/2), trough-crossbedded fluvial sandstone, commonly calcareous, clayey, silty, or conglomeratic; also includes mudstone, siltstone, and claystone of overbank deposits. Lower half consists of interbedded, thin, in part calcareous, fine-grained beds, including grayish-red (10R4/2) and dark-reddish-brown (10R3/4) claystone, pale-olive (10Y6/2) and light-greenish-gray (5GY7/1) clayey siltstone, cream-colored to very light gray (N8) and greenish-gray (5G8/1), fine- to very fine grained sandstone and white platy limestone, mainly of lacustrine and eolian origin. Lower part of member contains relatively few medium- to coarse-grained sandstone lenses of fluvial origin. Content of pink potassium feldspar in sandstone near the base is negligible but increases upward in section, so that stratigraphically higher sandstone beds approach the feldspathic composition of arkose and the character of overlying Westwater Canyon Member (mappable units of this character are shown as unit Jmw where greater than 5 m thick). Good sorting and uniform fine grains distinguish eolian sandstone units. Dusky red color of claystone is early diagenetic in contrast to the secondarily reduced, more permeable, greenish- to olive-gray siltstone and mudstone. Intertongues with underlying sandstone unit. Thickness 40–70 m

GEOLOGIC QUADRANGLE MAP  
Published by the U.S. Geological Survey, 1990

FIGURE 6

shale  
baseline

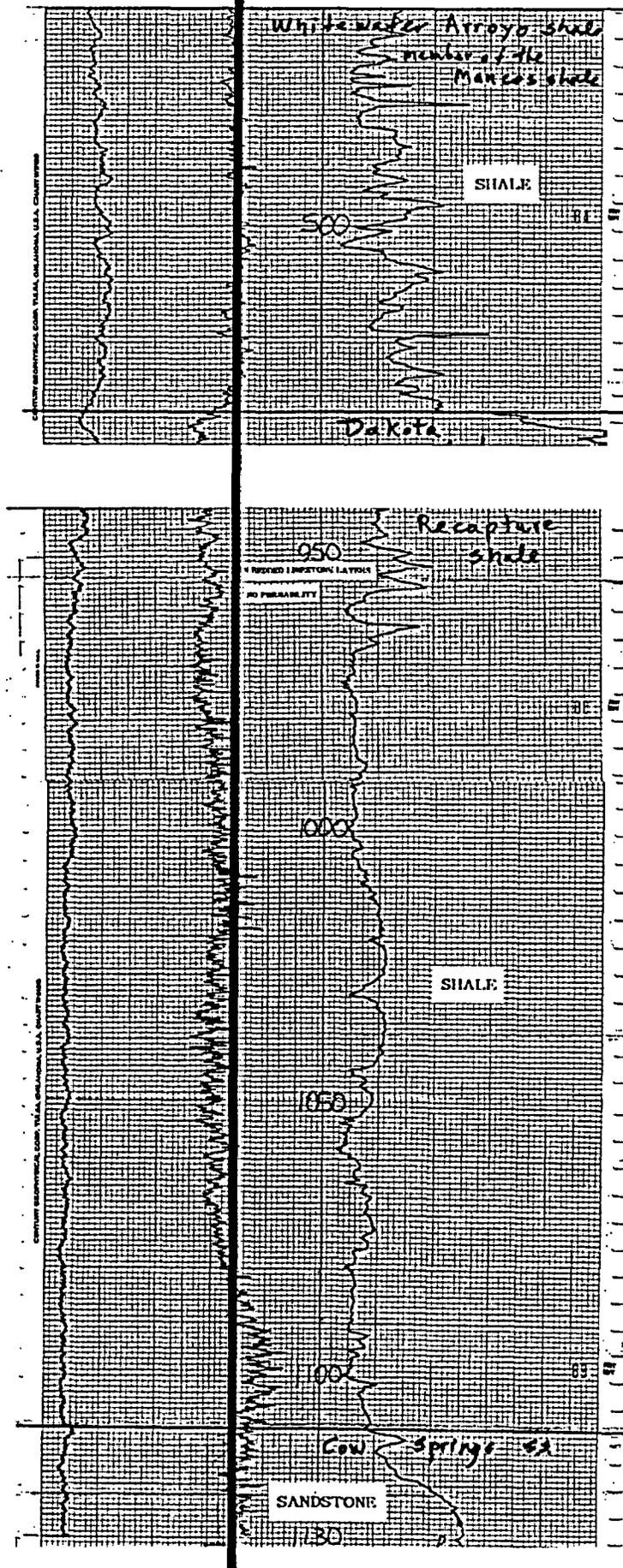


FIGURE 7

shale  
baseline

geophysical log 8-02.8/17

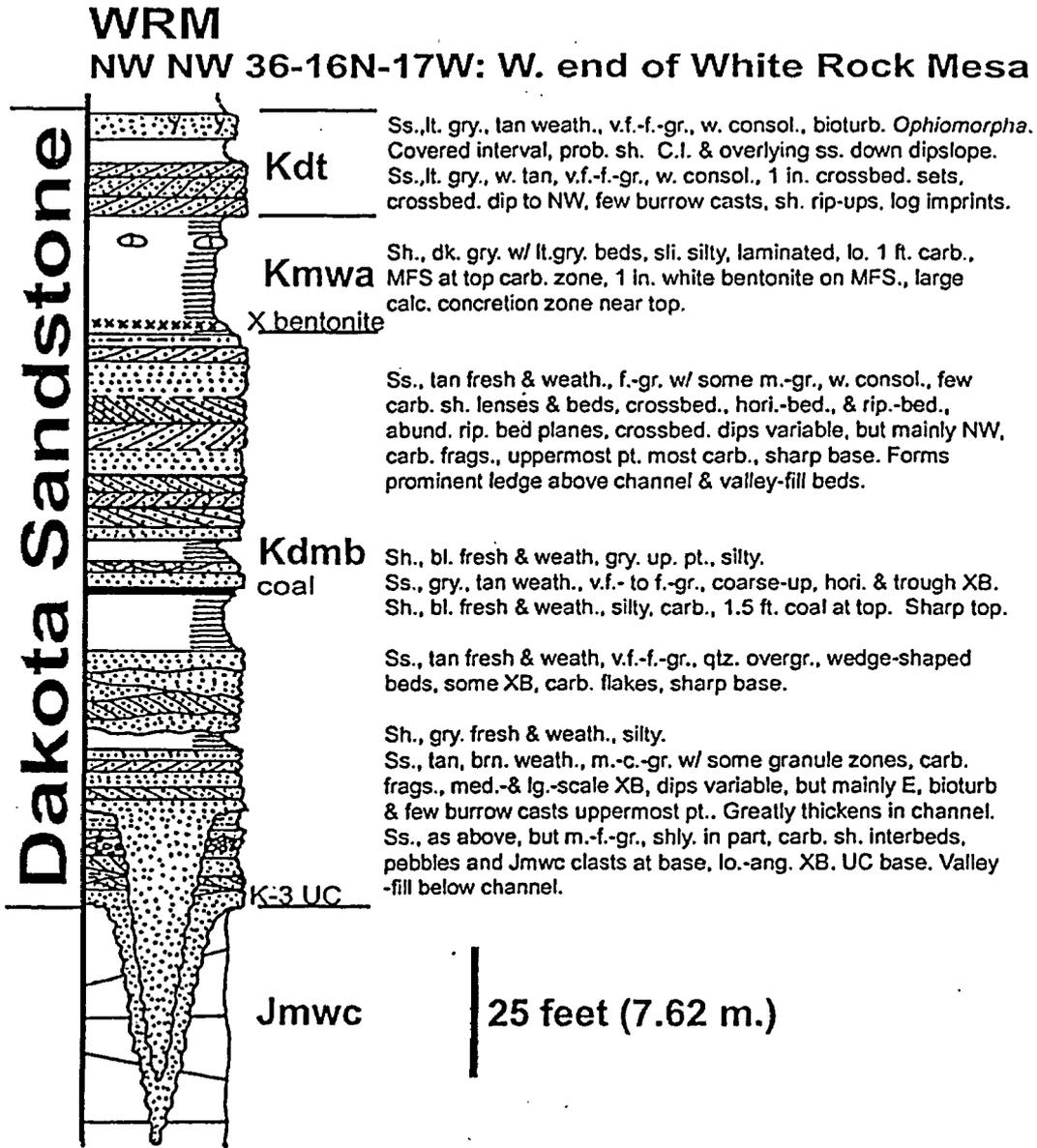


FIGURE 3. Measured section and description of Dakota Sandstone and intertongued Whitewater Arroyo Shale Tongue of Mancos Shale at west end of White Rock Mesa (Stop 5, Day 2, NMGS Field Conference, 2003), McKinley County, NM.

FIGURE 8

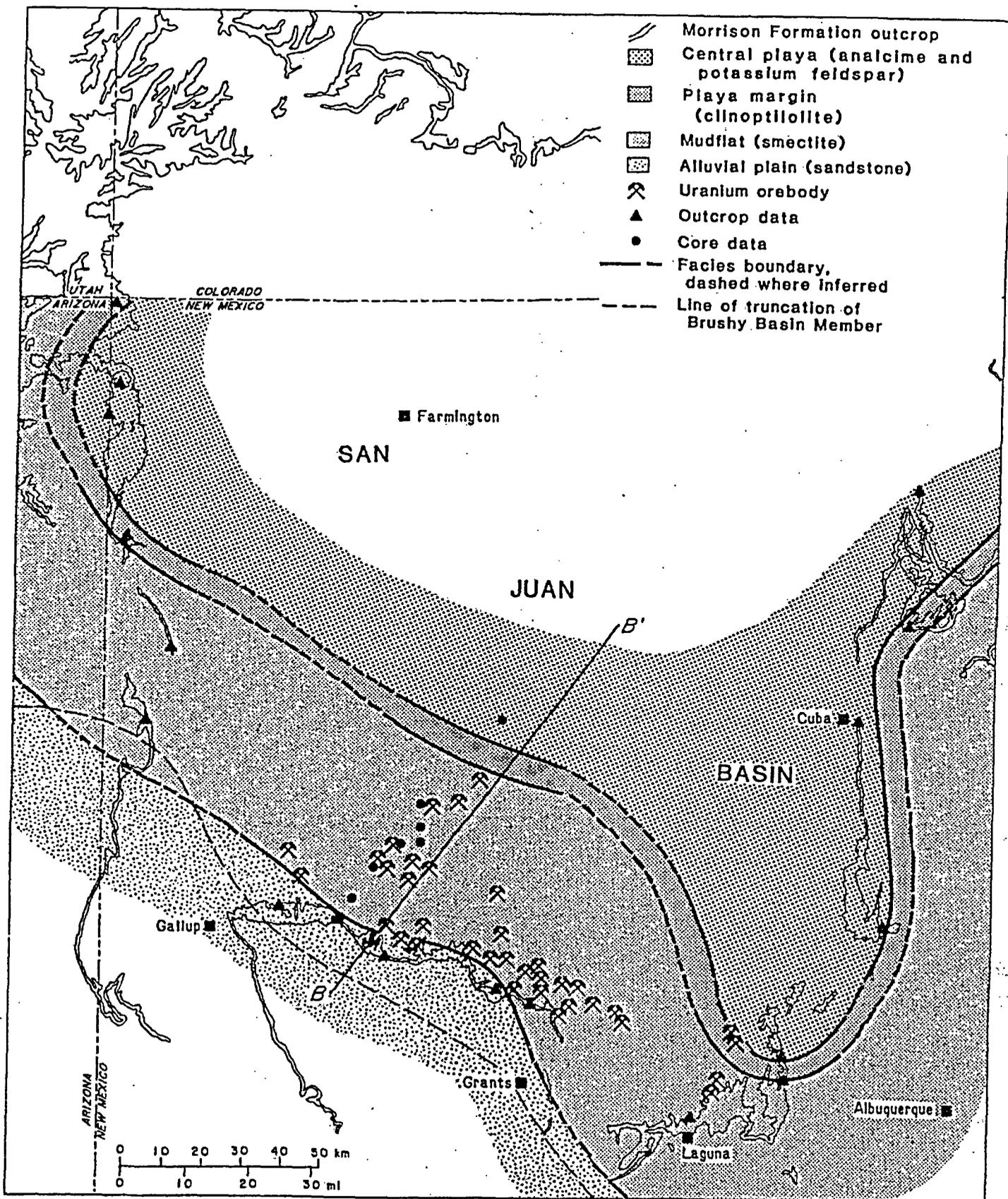


Figure 6: Generalized facies distribution for Brushy Basin Member of the Morrison Formation, San Juan basin. This facies pattern reflects development of a saline-alkaline lake in a closed-basin setting. (From Turner-Peterson, 1985). Line B—B' is shown on Figure 14.

FIGURE 9



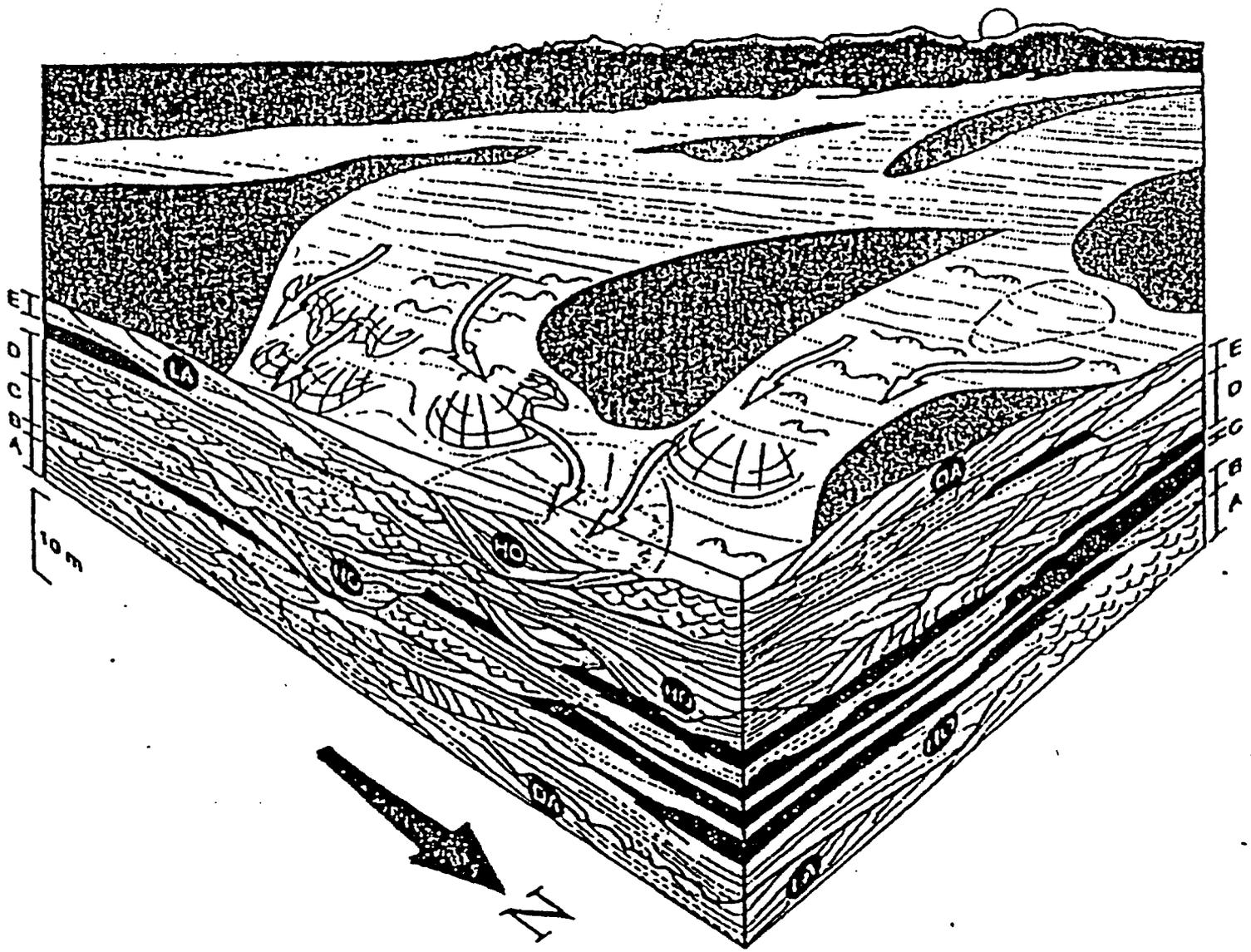


FIG. 18.—The large-scale architectural model of the Westwater Canyon Member fluvial system. The block diagram illustrates waning-stage flow, seen looking toward the southwest and the Late Jurassic magmatic arc. The sandstone units produced between each avulsive event of the channel belt are approximately 5 m thick, and are bounded by laterally-extensive fifth-order bounding surfaces. The width of the sandstone sheets is most likely >1 km. The sandstone bodies can be either single or composite channelbelt sandstones, depending on their vertical stacking, as shown by the examples of sandstone sheets A to E. The large hollows (labelled HO) within the sandstone sheets are interpreted as channel-confluence scours produced downstream of emergent channel sand bars, which in turn produce low-amplitude lateral accretion (LA) and downstream accretion (DA) deposits.

FIGURE 11

From Cowan (1991), Figure 18

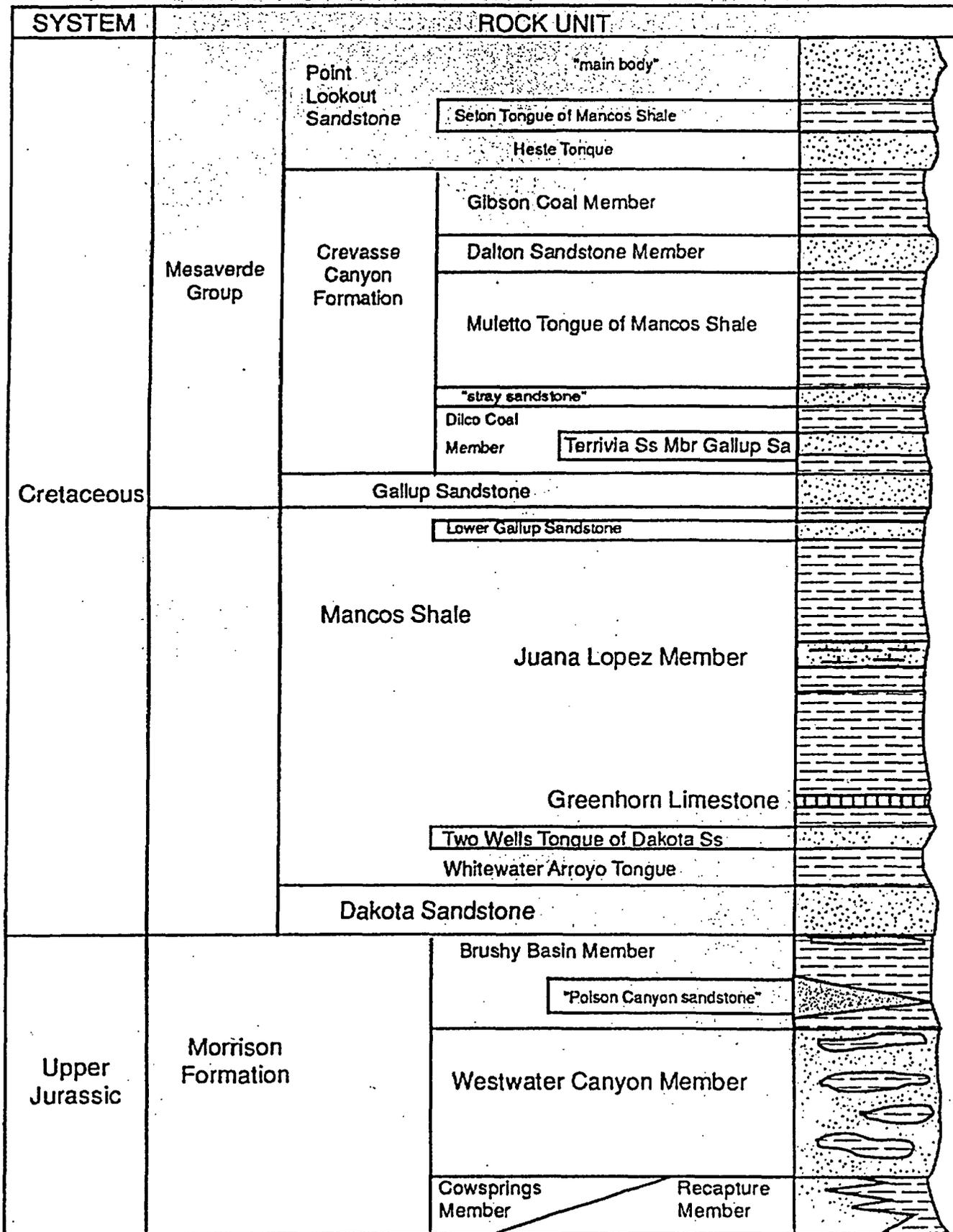
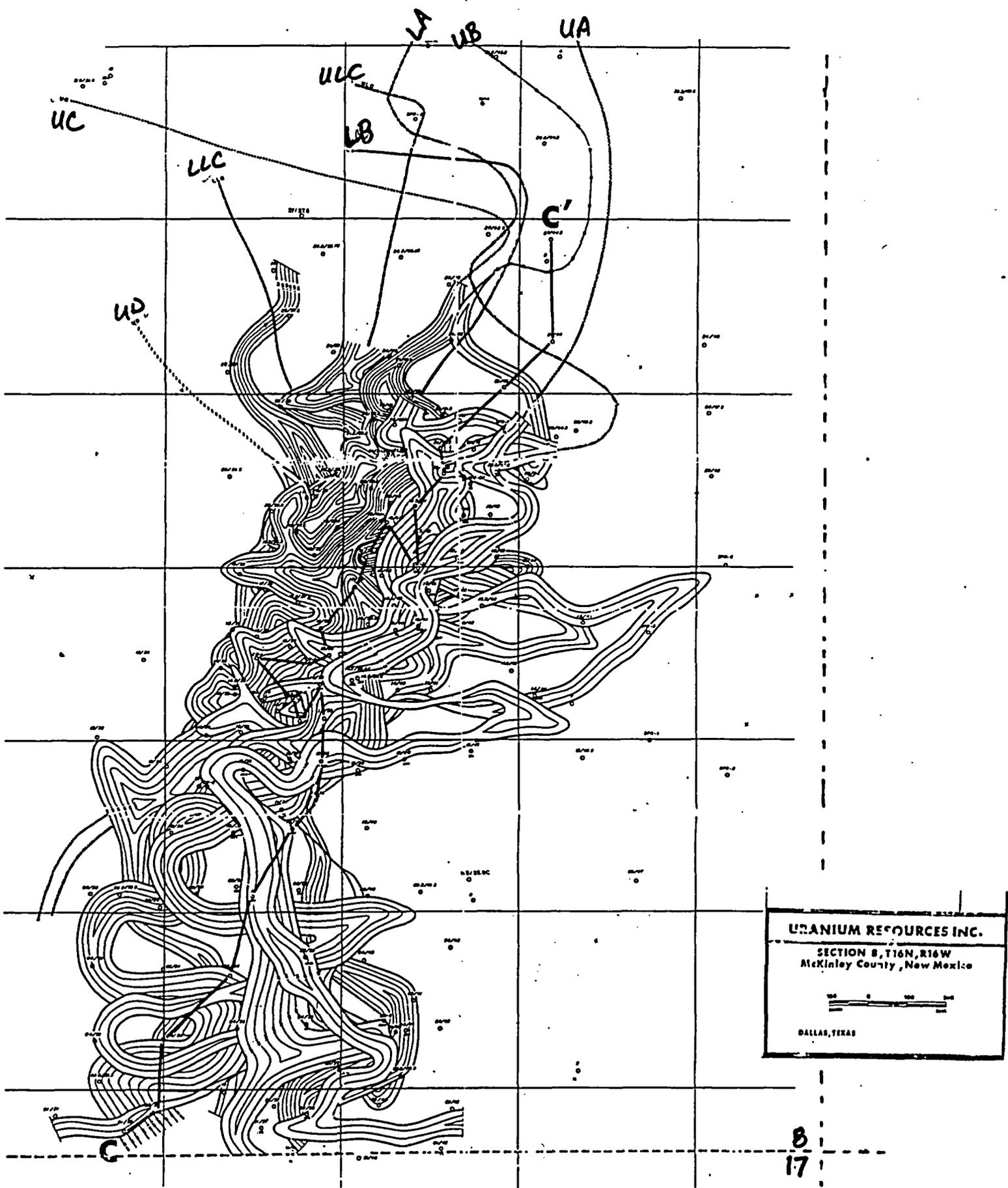


Figure 3.5. Stratigraphic column of the Unit 1 and Crownpoint sites.



**FIGURE 13**

Adapted from HRI Section 8 Restoration Action Plan (November 17, 2000), Attachment E-2-2.

# EXHIBIT E

## JURASSIC STRATIGRAPHY IN WEST-CENTRAL NEW MEXICO

SPENCER G. LUCAS AND ANDREW B. HECKERT

New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104

**ABSTRACT.**—Jurassic strata in west-central New Mexico encompass part of the southern edge of the Jurassic outcrop belt in the Western Interior. Some of the Jurassic units pinch out or are truncated southward in west-central New Mexico, so that in the southernmost reaches of the Jurassic outcrop belt the entire Jurassic section is merged eolian sandstones. Therefore, a dual lithostratigraphic nomenclature needs to be used for Jurassic strata in west-central New Mexico, one that reflects the two different lithofacies belts. For convenience, we refer to these as the water-deposited and the eolian lithofacies belts. The Jurassic section in the water-deposited lithofacies belt is (in ascending order) the Entrada Sandstone (Dewey Bridge and Slick Rock members), Todilto Formation (Luciano Mesa and Tonque Arroyo members), Summerville Formation, Bluff Sandstone (main body and Recapture Member), Acoma Tongue of the Zuni Sandstone and Morrison Formation (Salt Wash, Brushy Basin and Jackpile members). In the eolian lithofacies belt, the entire Jurassic section is assigned to the Zuni Sandstone. The "Iyanbito Member" of the Entrada Sandstone is Triassic strata of the Wingate Sandstone and thus is removed from the Entrada, and the name Iyanbito Member is abandoned. The lithostratigraphy we advocate for Jurassic strata in west-central New Mexico is parsimonious; it reflects regional lithostratigraphic geometry, embodies sound application of stratigraphic principles and is both practical and useful to geologists. It provides a sound basis for a Jurassic sequence stratigraphy in west-central New Mexico that recognizes four regional unconformities: J-2 (base of Entrada and Zuni sandstones), J-3 (base of Todilto Formation), J-5 (base of Salt Wash Member of Morrison Formation) and K-0 (base of Cretaceous Dakota Sandstone).

### INTRODUCTION

Jurassic strata are well exposed in west-central New Mexico, principally along the northern flank of the Zuni uplift and the eastern edge of the Colorado Plateau (Fig. 1). First assigned a Jurassic age by Marcou (1858), and a focal point of Dutton's (1885) classic study of the geology of the Zuni plateau, the Jurassic strata of west-central New Mexico have yielded uranium, groundwater and building stone that made them a major focus of geologic study, especially in the latter half of the twentieth century. Extensive stratigraphic analysis and mapping were an integral part of this study, and have led to a complex stratigraphic nomenclature that has both evolved through time and been a major source of debate (Fig. 2). Here, we review the Jurassic stratigraphy of west-central New Mexico to advocate a Jurassic stratigraphic nomenclature that reflects regional lithostratigraphic geometry, embodies sound application of stratigraphic principles and is both practical and useful to geologists.

### PREVIOUS STUDIES

Various articles review previous studies of the Jurassic stratigraphy of west-central New Mexico (e.g., Baker et al., 1936; Condon and Peterson, 1986; Lucas and Anderson, 1998; Lucas, 2003), obviating the need for an extensive review here. Instead, we briefly trace the development of Jurassic stratigraphic concepts and nomenclature between the key works of Dutton (1885), Darton (1928a,b), Baker et al. (1936, 1947), Dane and Bachman (1965), Condon and Peterson (1986) and Lucas and Anderson (1998; Fig. 2).

Marcou (1858) essentially "guessed" a Jurassic age for some of the strata exposed in west-central New Mexico, and Dutton (1885) followed suit, lacking any compelling evidence to assign any of the strata to the Jurassic (Lucas, 2001, 2003). Dutton (1885) coined the names Wingate Sandstones (considered by him to be Triassic) and Zuni Sandstones for strata in west-central New Mexico now deemed Jurassic (Lucas, 2003; Fig. 2).

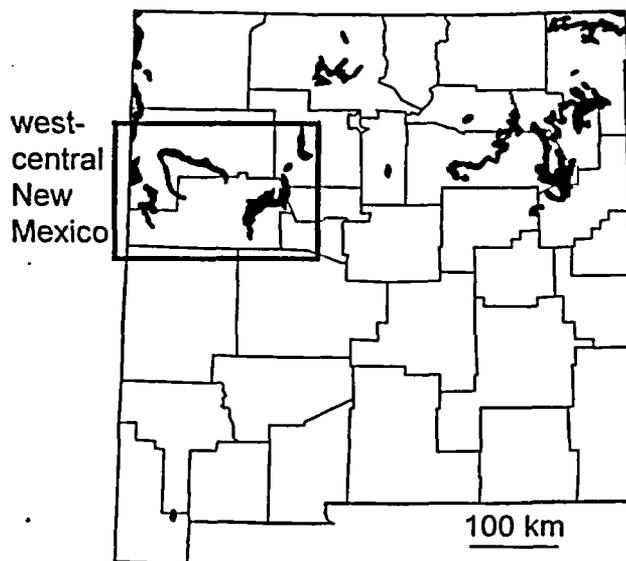


FIGURE 1. Outcrops of Jurassic strata in New Mexico (after Dane and Bachman, 1965) with the area of west-central New Mexico indicated.

Darton's (1928a) summary of the geology of New Mexico represented nearly half a century of work after Dutton, and his view of the Jurassic stratigraphy of west-central New Mexico was based primarily on the work of Gregory (1917). Thus, Gregory's (1917) mistake of believing that the Todilto Formation underlies the Navajo Sandstone was repeated by Darton (Fig. 2). The mistake was based on miscorrelation of the eolian sandstone interval above the Todilto Formation in west-central New Mexico (Bluff Sandstone of this paper) with the Navajo Sandstone of eastern Arizona, a much older and stratigraphically lower eolian sandstone. Otherwise, Darton (1928a) recognized the Wingate Sandstone *sensu* Dutton but did not use the term Zuni Sandstone. Instead, he assigned this part of the section to the Todilto, Navajo

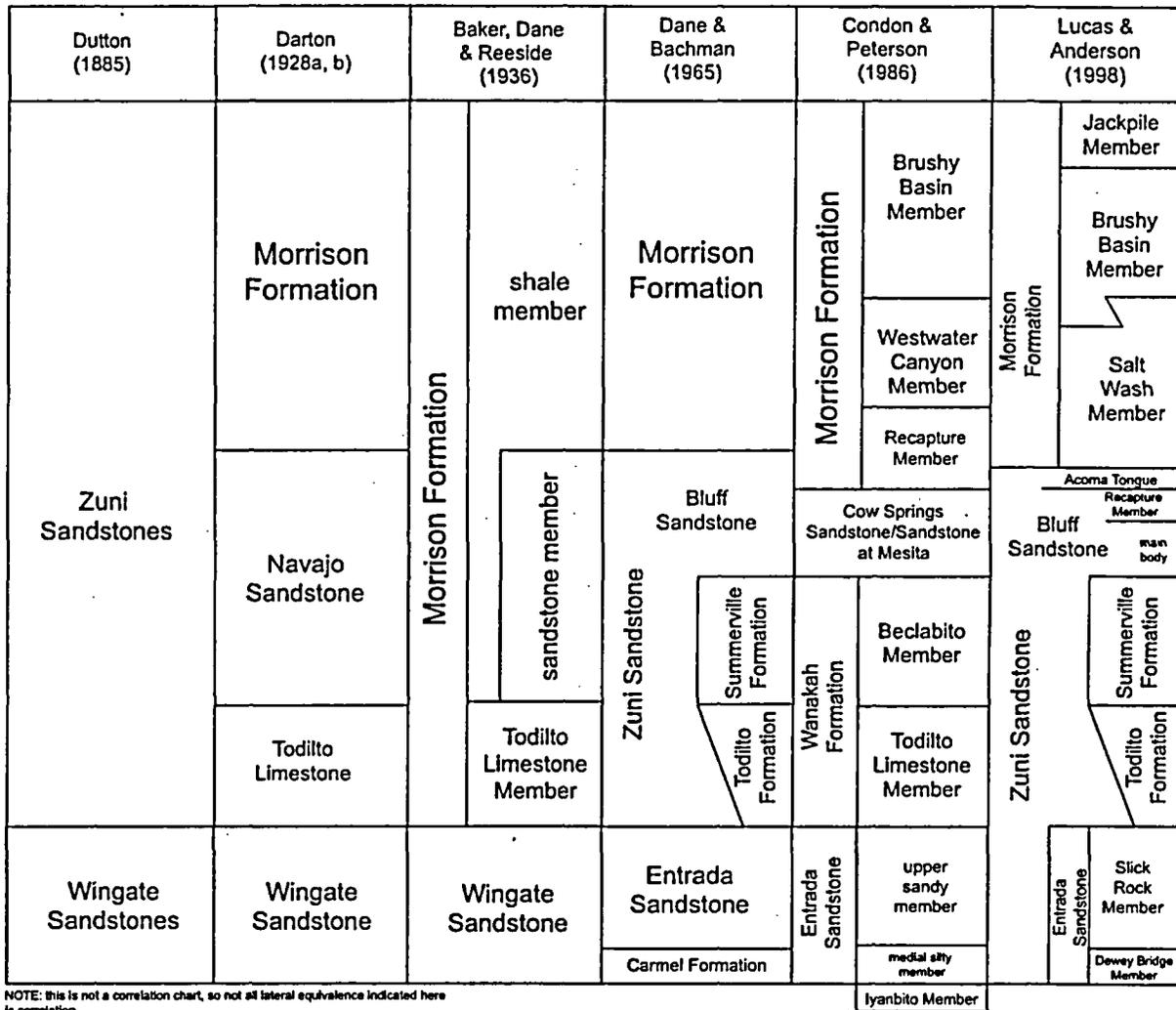


FIGURE 2. Development of Jurassic stratigraphic nomenclature in west-central New Mexico. The stratigraphy advocated here is that of Lucas and Anderson (1998).

and Morrison formations (though note that Darton thought the Morrison to be most likely of Cretaceous age; Fig. 2).

The classic monograph by Baker, Dane and Reeside (1936) was the first explicit attempt to assemble a synthetic Jurassic stratigraphy of much of the Colorado Plateau. This monograph provided an extensive and useful review of earlier work. It corrected some earlier mistakes; for example, the Navajo Sandstone was correlated correctly so that the Todilto was placed much higher in the section, correcting Gregory's errors (Fig. 2). However, miscorrelation of the Wingate Sandstone, as had been done by Gregory (1917), continued. Also, the Morrison base was moved down to include the Todilto and all overlying Jurassic strata (Fig. 2). This bizarre decision lumped together units that are very different lithologically, but it may have been advocated to avoid problems of correlation within this interval.

Baker et al. (1936) also made a significant error (see their plate 2) in believing that the entire San Rafael Group of Utah (Carmel,

Entrada and Summerville formations of Gilluly and Reeside, 1928) pinched out between the Morrison and Wingate in the Four Corners, north of Red Rock, Arizona. Therefore, they believed that the San Rafael Group of southeastern Utah was pinching out to the south (their fig. 7), so that in west-central New Mexico Dutton's Wingate Sandstone was much older than (stratigraphically lower than) the San Rafael Group of Utah.

This and other errors were corrected in 1947, when Baker, Dane and Reeside, in a five-page-long published note, repudiated the principal conclusions of their 66-page-long, 1936 monograph. Thus, they removed the Todilto and Summerville from the Morrison, and at least in Colorado and New Mexico, considered them members of Burbank's (1930) Wanakah Formation. They also agreed with Heaton (1939) on a broader distribution of the Entrada Sandstone, and in particular, concluded that the Red Rock cliffs at Fort Wingate, type section of Dutton's Wingate Sandstone, were correlative to Gilluly and Reeside's Entrada Sandstone. Dutton was dead, and

Reeside had been party to two major blunders—unnecessarily naming the Entrada (with Gilluly in 1928) and miscorrelating it regionally (with Baker and Dane in 1936). The simplest solution, which would have obeyed priority, would have replaced the name Entrada with Wingate and given a new name to the lower eolianite of the Glen Canyon Group that had erroneously been called Wingate. Instead, Baker et al. (1947, p. 1667) argued that “through use in numerous publications, they [Wingate and Entrada *sensu* Baker et al., 1936] are firmly entrenched in geologic literature and are well known to many geologists....the abandonment of this nomenclature through the application of the principles of priority would be unfortunate and confusing.” Therefore, Baker et al. (1947) continued usage of Wingate Sandstone for the lower eolianite of the Glen Canyon Group, abandoned Dutton’s type Wingate locality, and called the type Wingate strata Entrada. This actually did much violence to usage, at least in New Mexico, where Wingate Sandstone *sensu* Dutton (1885) was well entrenched in the geologic literature (e.g., Darton, 1928a; Heaton, 1939; Dobrovolsky et al., 1946) and had even been embodied in Darton’s (1928b) geologic map of New Mexico. It would have been simpler to follow priority.

By the 1950s, a new consensus had emerged on the Jurassic stratigraphy on the southern Colorado Plateau. This was the official U. S. Geological Survey stratigraphy, and it was embraced eagerly by most of those who worked on the economic geology of the Jurassic strata, especially in the uranium fields. This regional stratigraphy was that of Gilluly and Reeside (1928) and the corrected regional correlations of Baker et al. (1947), with some of the gaps in their coverage filled by Harshbarger et al. (1957). Dane and Bachman (1965), in their state geologic map of New Mexico, well reflected the 1960s consensus on Jurassic stratigraphy in west-central New Mexico (Fig. 2). They thus recognized a Jurassic section of Carmel, Entrada, Todilto, Summerville, Bluff and Morrison formations laterally equivalent in part to eolian sandstones they called Zuni Sandstone and lower San Rafael Group strata they referred to the (now forgotten) Thoreau Formation of Smith (1954; Fig. 2).

It is interesting to compare the Jurassic stratigraphy of Dane and Bachman (1965) with that of Lucas and Anderson (1998), which is the stratigraphy advocated here (Fig. 2). At the formation level, the two stratigraphic schemes are nearly identical. So, how can we explain the very different stratigraphy developed by the U. S. Geological Survey during the 1970s and 1980s (Fig. 2) and well summarized by Condon and Peterson (1986)? The explanation, as detailed in articles by Anderson and Lucas (1992, 1994, 1995, 1996, 1997, 1998), Lucas and Anderson (1996, 1997, 1998), Lucas and Woodward (2001) and Lucas et al. (1999, 2001), is that numerous conceptual, methodological and empirical errors in the work of U. S. Geological Survey stratigraphers Pippingos, O’Sullivan, Peterson, Condon and their collaborators set back by nearly three decades the development of a workable Jurassic stratigraphy on the southern Colorado Plateau.

The conceptual errors included confounding lithostratigraphy and chronostratigraphy. Thus, in the scheme of regional Jurassic unconformities proposed by Pippingos and O’Sullivan (1978), the unconformities were assumed to be time boundaries. The J-5 unconformity was thus equated with the Middle-Late Jurassic

boundary. When evidence was presented that part of the upper Summerville Formation is of Late Jurassic age, the J-5 unconformity had to be placed within the Summerville despite a total lack of physical stratigraphic evidence of an unconformity within the formation.

Methodological errors were many. The most obvious included using preoccupied names and renaming the same stratigraphic unit over and over again. A good example is the Survey stratigraphers’ insistence on using the preoccupied name Wanakah Formation and their unnecessary renaming of the Bluff Sandstone, so that this unit has at least four names (see below). Empirical errors were legion and are best exemplified by the myriad miscorrelations of the Entrada Sandstone by O’Sullivan, discussed by Lucas et al. (2001) and reviewed below. The article in this guidebook by O’Sullivan (2003) continues a tradition of misrepresentation and miscorrelation of Jurassic strata at both the outcrop and the regional scale.

The Jurassic stratigraphy in west-central New Mexico advocated here (Fig. 2) is that of Anderson and Lucas, published in a series of articles between 1992 and 1998 (see bibliography), with some minor modifications based on data gathered since then. Indeed, this article is largely a summary of the Anderson-Lucas Jurassic stratigraphy in west-central New Mexico, and more extensive discussion and justification of it can be found in their articles.

## LITHOSTRATIGRAPHY

West-central New Mexico encompasses part of the southern edge of the Jurassic outcrop belt in the Western Interior (e.g., McKee et al., 1956). Thus, some of the Jurassic stratigraphic units pinch out or are truncated southward in west-central New Mexico, so that in the southernmost reaches of the Jurassic outcrop belt the entire Jurassic section is merged eolian sandstones. Therefore, a dual lithostratigraphic nomenclature needs to be used for Jurassic strata in west-central New Mexico, one that reflects the two different lithofacies belts (Fig. 2). For convenience, we refer to these as the water-deposited and the eolian lithofacies belts, and review lithostratigraphy in each.

### Water-deposited Lithofacies Belt

In west-central New Mexico, the water-deposited lithofacies belt begins at about Interstate Highway 40 and extends northward into the San Juan Basin. We define this lithofacies belt to include several water-deposited Jurassic units, the Todilto, Summerville and Morrison formations, not found to the south in the eolian lithofacies belt. These water-deposited units are intercalated with eolian units, so that the water-deposited lithofacies belt consists of a section of Middle and Upper Jurassic eolian and water-deposited strata (Fig. 2).

### Entrada Sandstone

The dominantly eolian Entrada Sandstone is at the base of the Jurassic section across much of west-central New Mexico. Still, the stratigraphic relationships at the base of the Jurassic section in west-central New Mexico remain a contentious problem. As noted above, Dutton (1885) applied the name Wingate Sandstones to the

oldest Jurassic strata near Fort Wingate in McKinley County. More than 40 years later, in Utah, Gilluly and Reeside (1928) named the same lithostratigraphic unit the Entrada Sandstone. Baker et al. (1936) miscorrelated Dutton's type Wingate and Gilluly and Reeside's type Entrada to such an extent that Wingate came to be applied to a much older eolian sandstone interval on the southern Colorado Plateau, and Dutton's type Wingate came to be called Entrada!

Condon and Peterson (1986) well summarized the current thinking of the U.S. Geological Survey on Entrada stratigraphy. They followed Green (1974) and recognized a tripartite Entrada Sandstone in west-central New Mexico—"Iyanbito," medial silty and upper sandy members—that has been mapped by several workers, including Cooley et al. (1969). Very recently, Robertson and O'Sullivan (2001) named the "medial silty member" the Rehoboth Member of the Entrada Sandstone, and indicated correlation of the upper sandy member with the Slick Rock Member (Wright et al., 1962) of the Four Corners (also see O'Sullivan, 2003).

We previously presented, in preliminary form, a very different view of Entrada regional stratigraphy (Heckert and Lucas, 1998; Lucas and Anderson, 1998; Lucas et al., 2001). We thus exclude the "Iyanbito Member" from the Entrada; as Harshbarger et al. (1957) and Cooley et al. (1969) well demonstrated, it is the equivalent of the "Lukachukai Member" of the Wingate Sandstone (*sensu* Harshbarger et al., 1957) and therefore a unit of Late Triassic age beneath the J-2 unconformity.

The "medial silty member" of the Entrada in west-central New Mexico is equivalent to the Dewey Bridge Member of Wright et al. (1962), and the upper sandy member is equivalent to their Slick Rock Member. Therefore, the Rehoboth Member of Robertson and O'Sullivan (2001) is an unnecessary junior synonym of the Dewey Bridge Member (Lucas et al., 2001).

We have a detailed database upon which to base our stratigraphic conclusions that consists of measured sections from the type sections of the Dewey Bridge (southeastern Utah) and Slick Rock (southwestern Colorado) members through the Four Corners southward along the Chuska Mountains and across west-central New Mexico (Fig. 3). These sections indicate the following:

1. The "Iyanbito Member" (= "lower sandy member" of Cooley et al., 1969) rests with profound unconformity (Tr-5 unconformity) on the Upper Triassic Owl Rock Formation of the Chinle Group in west-central New Mexico (also see Green, 1974). To the northwest, along the western flank of the Chuska Mountains, the stratigraphic position of the "Iyanbito Member" is occupied by the Wingate Sandstone or the Wingate Sandstone plus Rock Point Formation. Nowhere outside of west-central New Mexico in the Entrada outcrop belt, including the type Entrada section in Utah, is there a stratigraphic interval of the Entrada equivalent to the "Iyanbito Member."

2. Stratigraphic position, bedforms and lithotypes of the "Iyanbito Member" and Wingate are essentially identical (Harshbarger et al., 1957). Particularly significant are thin beds of siltstone, sandy mudstone and chert pebbles that are common in the Iyanbito Member and also known in the Wingate. Furthermore, compare lithologic descriptions of the "Iyanbito Member" and Wingate Sandstone provided by Robertson and O'Sullivan (2001, p. 59 and 65, respectively); they indicate lithologic identity.

3. The contact of the "Iyanbito Member" with the overlying "medial silty member" of the Entrada is a sharp surface marked by a substantial change in grain size and bedforms. Indeed, at the type section of the "Iyanbito Member" (Fig. 3, Appendix 1), fissures and desiccation features in the top of the "Iyanbito Member" are filled with sediment from the overlying Dewey Bridge Member. This readily traceable and mappable contact is the J-2 unconformity, and there is significant stratigraphic relief on the J-2 surface regionally (Figs. 3-4).

4. Robertson and O'Sullivan (2001) correctly describe Entrada depositional systems as "quiet," "low-energy," "lacustrine," "eolian" and "sabkha." So, without unconformities, how can they account for thickness variations in the Iyanbito from 0 to 45 m over short distances? An unconformity-bounded "Iyanbito" Member best explains these thickness variations.

We conclude that the "Iyanbito" is unconformity bounded and equivalent to the Wingate, which is also unconformity bounded where overlain by the Entrada. Iyanbito is an unnecessary synonym of Wingate and should be abandoned.

Robertson and O'Sullivan (2001) and O'Sullivan (2003) reject our correlation (and assignment) of the medial silty member of the Entrada Sandstone in west-central New Mexico to the Dewey Bridge Member of the Entrada of Wright et al. (1962). Instead, Robertson and O'Sullivan (2001) and O'Sullivan (2003) correlate the "middle sandstone" and overlying "red member" of the Entrada in southeastern Utah to the "Iyanbito" and "medial silty" (= "Rehoboth") members, respectively. Not only do they fail to demonstrate this correlation, but our fieldwork indicates it is incorrect.

At Bluff in southeastern Utah (e.g., secs. 29-30, T40S, R21E, San Juan County), the basal unit of the Entrada is an ~ 14 m thick, bench-forming eolian sandstone that rests directly on the Carmel Formation; this is the "middle sandstone" of the Entrada of O'Sullivan (1980), and it is the base of the Slick Rock Member locally. Beds overlying it are ~ 19 m of trough crossbedded sandstone, locally of reddish color, that are the "upper red" (= "red member") of O'Sullivan (1980). Thus, strata of the "red member" at Bluff are typical Slick Rock Member eolianites, and there is no reason to correlate them to the lithologically different "medial silty member" ("Rehoboth Member") to the south, especially as the "red member" at Bluff is well above the Slick Rock Member base.

In the Dry Wash area of southeastern Utah (e.g., the Black Steer Knoll section of O'Sullivan [1980] in sec. 8, T36S, R21E, San Juan County), the Entrada Sandstone is ~ 26 m thick (this is the "middle sandstone" of O'Sullivan). The overlying "red member" of O'Sullivan is reddish brown sandy mudstone and siltstone at the base of the Summerville Formation, not a part of the Entrada Sandstone (cf. Anderson and Lucas, 1992).

Furthermore, at Church Rock in southeastern Utah (sec. 24, T31S, R23E, San Juan County), the unit O'Sullivan (1996) identified as the "red member" of the Entrada actually is the Carmel Formation, and the unit he labeled "middle sandstone" is the Navajo Sandstone (e.g., Weir and Dodson, 1958). Thus, it is clear that O'Sullivan (1980, 1996) mis-correlated the unit he called the "red member" throughout southeastern Utah. At one section it is an interval of sandstone in the Slick Rock Member of the Entrada (at Bluff), at another it is the basal interval of the Sum-

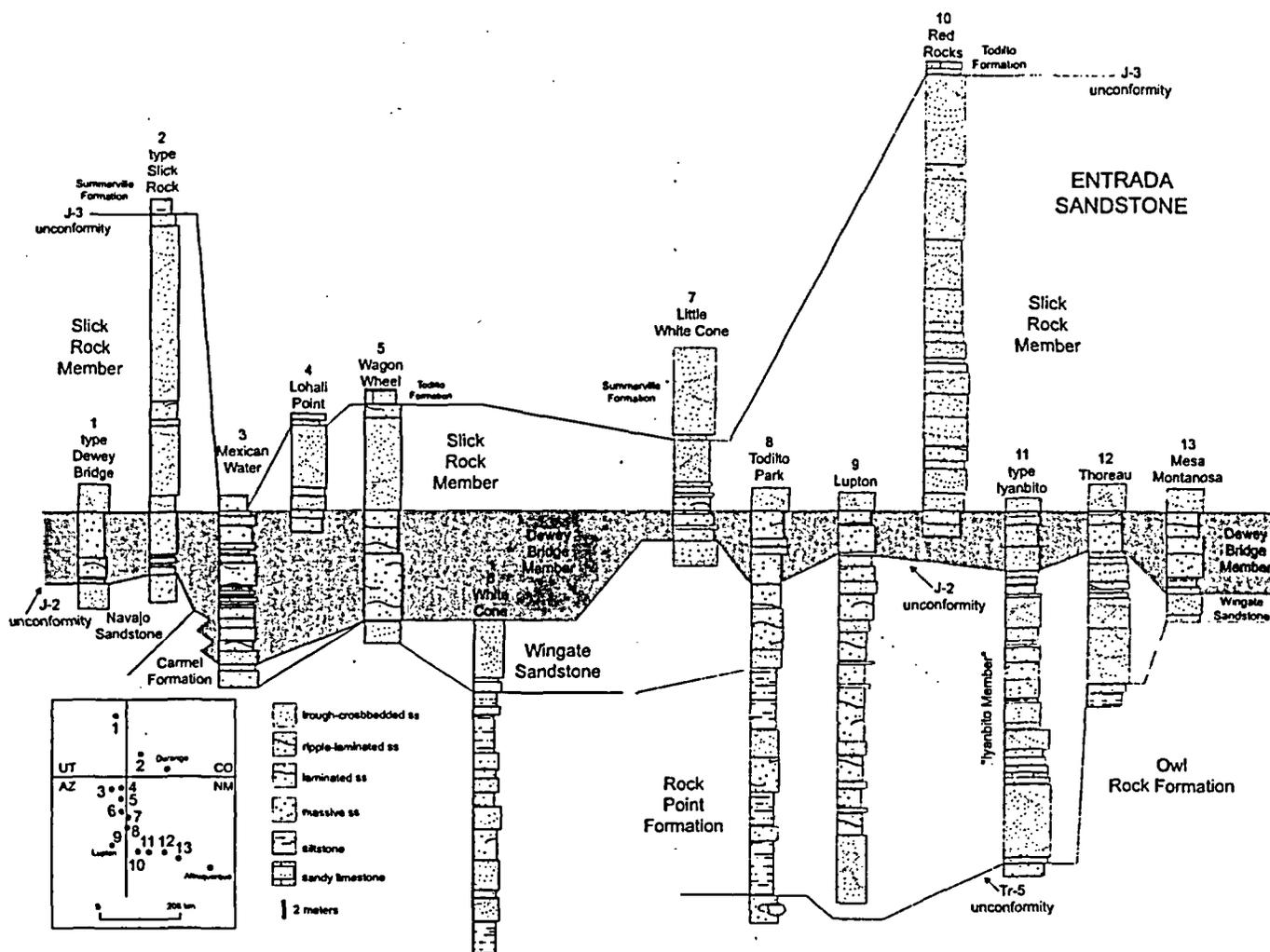


FIGURE 3. Measured stratigraphic sections of the Entrada Sandstone from the Four Corners through west-central New Mexico. See Appendix 2 for map coordinates of the measured sections.

merville Formation (at Dry Wash) and at another it is the Carmel Formation (at Church Rock). Robertson and O’Sullivan (2001) introduce the name Rehoboth Member for the “medial silty member” of the Entrada Sandstone and correlate it to the “red member.” Not only do they not document this correlation, but it is readily rejected because the type “Rehoboth” in west-central New Mexico is stratigraphically below the Slick Rock base, and the unit at Bluff in southeastern Utah to which they correlate it is above the Slick Rock base.

Instead, the correct correlation of the “Rehoboth Member” is that of Rapaport et al. (1952), Allen and Balk (1954), Harshbarger et al. (1957) and Cooley et al. (1969), among many others: it is laterally equivalent to and, in the northwest part of its outcrop area (e.g., at Mexican Water), immediately overlies the lower part of the Carmel Formation (Figs. 3-4). Thus, in west-central New Mexico, the “Rehoboth Member” is the lowest stratigraphic interval of the Entrada Sandstone and is largely equivalent to the

Carmel; the name Dewey Bridge Member already exists for this unit (Wright et al., 1962). “Rehoboth Member” is thus an unnecessary name and should be abandoned.

Moreover, compare O’Sullivan’s (2003, fig. 2) Entrada section at Mexican Water to our section at the same location (Fig. 3). His section lacks detail and suggests that the Carmel is overlain by a tripartite Entrada section consisting of ~9 m of “lower sandy member,” ~10 m of “Rehoboth Member” and ~6 m of “upper sandy member.” A more detailed look at this section (Fig. 3) reveals that the Carmel Formation is overlain by a 1.5-m-thick eolian sandstone that was mapped by Cooley et al. (1969, pl. 1, sheet 5) as the “lower sandy member” of the Entrada. We agree with Cooley et al. (1969) and O’Sullivan (2003) that this sandstone is at the base of the Entrada, but O’Sullivan’s (2003) thickness of this unit is greatly exaggerated. Above the basal eolian sandstone the entire Entrada section at Mexican Water is ~21 m thick and consists of thin eolian sandstone beds intercalated with

gypsiferous, red-bed siltstones and sandstones of characteristic Carmel lithotypes. Cooley et al. (1969) mapped this interval as the "middle silty member" of the Entrada and we interpret it as an intertonguing of upper Carmel and lower Entrada lithotypes at the transition from the Carmel lithosome to the Dewey Bridge Member of the Entrada Sandstone. There is no "upper sandy member" of the Entrada Sandstone at Mexican Water (Cooley et al., 1969), so O'Sullivan's (2003) section fundamentally misrepresents Entrada stratigraphy at that location.

Robertson and O'Sullivan (2001, fig. 3, also p. 63) and O'Sullivan (2003) acknowledge the equivalence of at least part of the Slick Rock Member of the Entrada in southeastern Utah and the "upper sandy member" of the Entrada in west-central New Mexico (Fig. 4). However, they do not apply the term Slick Rock Member to the "upper sandy member" for two reasons: (1) "the Slick Rock Member at its type locality is not overlain by the Todilto Limestone Member, nor by the equivalent Pony Express Limestone Member, of the Wanakah Formation" (p. 63-64); and (2) "the upper part of the Slick Rock Member in Dry Valley and possibly at the type locality is replaced southward by the Wanakah Formation" (p. 64). These are not valid reasons to justify not applying the term Slick Rock Member to the unit in west-central New Mexico that is physically continuous with the Slick Rock Member in southeastern Utah. Furthermore, Robertson and O'Sullivan (2001, p. 64) state that "the upper sandstone member at Gallup may represent, at most, a lower tongue of the type Slick Rock." Yet, the type Slick Rock Member overlies the Dewey Bridge Member, though Robertson and O'Sullivan claim their Rehoboth Member, which is beneath the "upper sandy member" at Gallup, is not correlative to the Dewey Bridge Member, but to a stratigraphically higher unit, well above the base of the Slick Rock Member. Both correlations advocated by Robertson and O'Sullivan (2001) cannot be correct. Instead, the correct correlation indicates that the Entrada Sandstone section at Gallup and throughout west-central New Mexico consists of Dewey Bridge Member overlain by Slick Rock Member (Figs. 3-4).

#### Todilto Formation

The type section of the Todilto Formation of Gregory (1917) is at Todilto Park, north of Fort Defiance near the New Mexico-Arizona border (Lucas et al., 2003). The unit is found across much of west-central New Mexico as a relatively thin interval of dark gray, kerogenic limestone, the Luciano Mesa Member of Lucas et al. (1995). However, in the eastern part of west-central New Mexico, north and east of Grants, near Mesita and Mesa Gigante, the upper, gypsum member of the Todilto Formation (Tonque Arroyo Member of Lucas et al., 1995) is also present above the Luciano Mesa Member and beneath the Summerville Formation.

Todilto Formation stratigraphy and sedimentation is well understood in west-central New Mexico due to recent work by Lucas et al. (1985, 2000), Armstrong (1995) and Kirkland et al. (1995), among others. In brief, the Luciano Mesa Member is up to 9 m thick and is mostly microlaminated, kerogenic limestone. Anderson and Kirkland (1960) suggested that the microlaminae form varved couplets and counted these couplets to estimate a duration of about 14,000 years for deposition of the Luciano

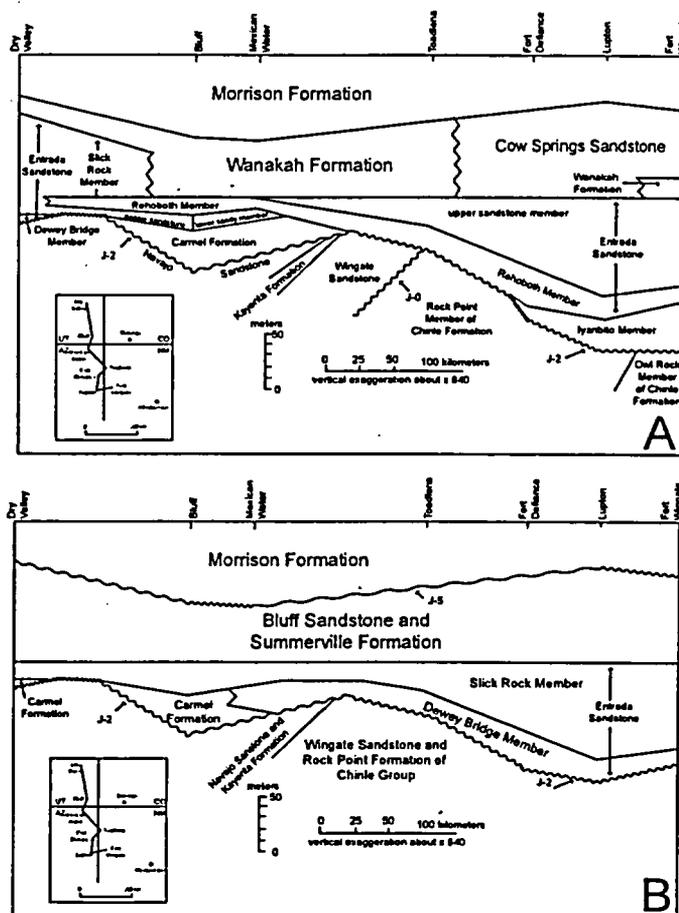


FIGURE 4. Correlation of some Jurassic rocks from southeastern Utah to west-central New Mexico. A, From Robertson and O'Sullivan (2001, fig. 3). B, Correlation advocated in this paper.

Mesa Member. Fossils (ostracodes, insects, fishes), isotope geochemistry and sedimentologic analysis indicate deposition of the Luciano Mesa Member in a vast, paralic salina (Lucas et al., 1985, 2000; Kirkland et al., 1995). So-called stromatolites in the Todilto Formation of west-central New Mexico are, almost without exception, small-scale intraformational folds (e.g., Green, 1981, 1982). In west-central New Mexico, the upper, gypsum member of the Todilto Formation (Tonque Arroyo Member) is as much as 34 m thick and mostly massive and brecciated gypsum. It was deposited in a smaller evaporitic basin that resulted from the shrinking of the salina (Fig. 5).

Two stratigraphic issues needed to be briefly addressed with regard to the Todilto — its rank in the lithostratigraphic hierarchy and its regional correlation. To anyone familiar with the Todilto, it is one of the most distinctive lithostratigraphic units in the Jurassic section—a striking interval of limestone and/or gypsum in a section dominated by sandstone, siltstone and mudstone. The Todilto Formation is readily mapped as a formation-rank unit, and has been so mapped by many geologists. Despite this, workers of the U. S. Geological Survey have considered the Todilto

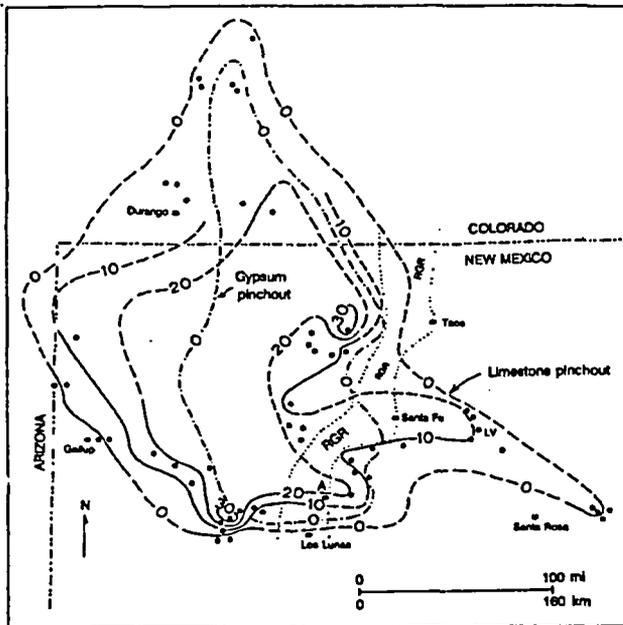


FIGURE 5. Approximate depositional limits of Jurassic Todilto limestone member (Luciano Mesa Member) and overlying Todilto gypsum member (Tonque Arroyo Member) (modified from Kirkland et al., 1995). Dotted outline is Rio Grande rift (RGR). A = Albuquerque, LV = Las Vegas. Structure contours for Todilto limestone member are in feet.

a member of the Morrison Formation (Baker et al., 1936) or a member of the "Wanakah Formation" (e.g., Condon and Peterson, 1986). Neither member designation is warranted, and we continue to recognize the Todilto as a unit of formation rank (Anderson and Lucas, 1992, 1994; Lucas and Anderson, 1997, 1998).

The Todilto Formation in west-central New Mexico occupies the same stratigraphic position as the Curtis Formation in east-central Utah (between the Entrada and Summerville formations). Both units are of Callovian age, but recent biostratigraphic data are insufficient to document a precise correlation. Nevertheless, stratigraphic position supports correlation of the Todilto and Curtis formations (e.g., Lucas and Anderson, 1997). Furthermore, the marine transgression recorded by the Curtis Formation represents a regional rise in base level that logically could have produced the Todilto salina, and this supports a Curtis-Todilto "event-stratigraphic" correlation. Thus, there are very good reasons to equate the Todilto base to the J-3 unconformity at the base of the Curtis (Lucas and Anderson, 1996, 1997). Recent arguments for catastrophic flooding at the onset of Todilto deposition (Ahmed Benan and Kocurek, 2000) are also consistent with equating the Todilto base to the J-3 surface.

Despite this, the U.S. Geological Survey has correlated the Todilto Formation with the middle part of the Entrada Sandstone in Utah (e.g., Pipiringos and O'Sullivan, 1978). The basis for this correlation actually has little to do with the Todilto or Curtis, but instead is an outgrowth of a miscorrelation of the Summerville Formation of Utah in which it is considered to be younger than its Colorado-New Mexico equivalent, the "Wanakah" Formation

(see later discussion). Anderson and Lucas (1992) presented a detailed refutation of this Summerville-"Wanakah" miscorrelation, discussed below. Therefore, we continue to advocate a Todilto-Curtis correlation.

#### Summerville Formation

In west-central New Mexico, the Summerville Formation is dominantly fine-grained, horizontally bedded sandstone with some thin interbeds of siltstone/maroon mudstone. Many beds are gypsiferous, and some thin beds of gypsum are present locally. As much as 49 m thick, the Summerville overlies the Todilto and is overlain by the Bluff Sandstone. The two members of the Summerville, Beclabito and Tidwell, recognized in eastern Utah and adjacent areas (Lucas and Anderson, 1997), cannot be distinguished in west-central New Mexico.

The Summerville Formation in west-central New Mexico is *physically continuous* with the Summerville Formation in the type area of southeastern Utah. Numerous surface and subsurface sections (e.g., O'Sullivan, 1980; Anderson and Lucas, 1992) document this continuity, and it was recognized by the 1950s. Thus, the name Summerville Formation was generally and justifiably applied to Jurassic strata in west-central New Mexico (e.g., Dane and Bachman, 1965). Despite this, beginning in the 1980s, workers of the U.S. Geological Survey replaced the name Summerville with "Wanakah," claiming that this unit in New Mexico is stratigraphically below (older than) the Summerville Formation in Utah. Anderson and Lucas (1992) presented a detailed refutation of this miscorrelation and rejected use of the preoccupied name Wanakah Formation in New Mexico or elsewhere. Indeed, Summerville strata are present across much of northern New Mexico and southern Colorado and have been assigned various names, including Wanakah, Bell Ranch and Ralston Creek. One name is sufficient for one mappable lithostratigraphic unit of consistent lithotype, so we continue to advocate use of the term Summerville Formation across its entire outcrop belt (Anderson and Lucas, 1992, 1994, 1996; Lucas and Anderson, 1997, 1998; Lucas et al., 1999; Lucas and Woodward, 2001).

#### Bluff Sandstone

In west-central New Mexico, the Bluff Sandstone gradationally overlies the Summerville Formation and consists of two distinct members. The lower, sandstone-dominated member is the equivalent of the type Bluff Sandstone near Bluff, Utah (Gregory, 1938). In west-central New Mexico, it is as much as 70 m of laminated and trough-crossbedded sandstone. This unit is the main body of the Bluff Sandstone (Lucas and Anderson, 1997). Above it in west-central New Mexico is a thinner (up to 36 m thick) interval of finer-grained sandstones and siltstones assigned to the Recapture Member of the Bluff Sandstone (Lucas and Anderson, 1997, 1998).

The main body of the Bluff is mostly of eolian origin, but unlike the Slick Rock Member of the Entrada Sandstone, the Bluff lacks thick sets of high-angle crossbeds with truncated upper boundaries (reactivation surfaces). Instead, it is dominated by horizontal bedforms (commonly 0.5-5.0 m thick) and indistinctly crossbedded facies. Bedforms and vertical facies stacking

suggest eolian sand sheet deposition and fluvial reworking on a broad, arid coastal plain of very low relief.

Previous nomenclature of the Bluff Sandstone interval in west-central New Mexico represents the most confused (and confusing) nomenclature in the entire Jurassic section. Thus, the Bluff has continually been renamed by workers of the U.S. Geological Survey who have been incapable of tracing it across west-central New Mexico and thus recognizing a single, sandstone-dominated lithosome between the Summerville Formation and Morrison Formation. Thus, the Bluff has been termed "Cow Springs Sandstone," "Horse Mesa Member of Wanakah Formation" and "Sandstone at Mesita," (e.g., Harshbarger et al., 1957; Condon and Peterson, 1986; Condon, 1989), all unnecessary synonyms of Bluff Sandstone. Bluff strata are also included in the "Recapture Member of the Morrison Formation" by many U.S. Geological Survey workers (e.g., Condon and Peterson, 1986). Indeed, unwarranted inclusion in the Morrison Formation of eolian beds of the Bluff or Acoma Tongue of the Zuni Sandstone by various workers of the U.S. Geological Survey (e.g., Condon and Peterson, 1986) has led to the misconception that eolianites are part of the lower Morrison Formation.

#### Acoma Tongue of the Zuni Sandstone

Locally, the sandstone interval above the Bluff Sandstone and below the Salt Wash Member of the Morrison Formation, as much as 70 m thick, is a boldly crossbedded eolian sandstone with easterly dipping foresets. This is the Acoma Tongue of the Zuni Sandstone of Anderson (1993), and it is present at various outcrops in west-central New Mexico from near Mesita to Church Rock to Zuni Pueblo. The Acoma Tongue is the stratigraphically highest eolianite in the Jurassic section and the top of the San Rafael Group.

#### Morrison Formation

For many years, the U.S. Geological Survey recognized three principal Morrison Formation members in west-central New Mexico (in ascending order): Recapture, Westwater Canyon and Brushy Basin. A fourth, uppermost Jackpile Member was later recognized after Owen et al. (1984) formalized the name (though, note that Condon and Peterson [1986] ignored the name Jackpile Member [Fig. 2], presumably because it was not formalized by employees of the U.S. Geological Survey).

Detailed work by Anderson and Lucas (1995, 1997, 1998) in southeastern Utah demonstrated that the type Recapture Member of the Morrison Formation of Gregory (1938) is best reassigned to the San Rafael Group as the upper member of the Bluff Sandstone (see above), and that Gregory's (1938) Westwater Canyon Member of the Morrison Formation is the same unit Lupton (1914) had earlier named Salt Wash Member. In light of these conclusions, the Morrison Formation in west-central New Mexico consists of three members (in ascending order): Salt Wash, Brushy Basin and Jackpile members (Fig. 6).

The Salt Wash Member is the sandstone-dominated lower part of the Morrison Formation, as much as 135 m thick in west-central New Mexico. It rests with distinct unconformity (J-5 unconformity) on either the Acoma Tongue of the Zuni Sandstone or the Recapture Member or the main body of the Bluff Sandstone

(Fig. 6). The absence of the Acoma Tongue and/or the Recapture Member at some sections is *prima facie* evidence of the unconformity, as is the scour-and-fill and substantial change in grain size and lithotypes at the base of the Salt Wash Member. The J-5 unconformity is a tectonosequence boundary that represents a significant tectonic reorganization of Jurassic depositional systems in the Western Interior.

The Salt Wash Member grades upward into the mudstone-dominated Brushy Basin Member, which is as much as 107 m thick in west-central New Mexico. The overlying Jackpile Member is as much as 91 m of mostly kaolinitic, crossbedded sandstone and silica-pebble conglomerate.

Three issues regarding the Morrison Formation merit brief comment:

1. Some workers have informed us that they believe the mineralogy of the basal Morrison Formation sandstone-dominated interval in west-central New Mexico is distinct from that of the type Salt Wash Member in east-central Utah, so that the interval in New Mexico merits a different member name. If this is the case, then Smith's (1954) name Prewitt Member of Morrison Formation has priority for this interval.

2. In west-central New Mexico, the Brushy Basin Member is mudstone dominated but includes significant fluvial channel deposits. It shows no demonstrable facies zonation of clay minerals, *contra* the claims of Turner and Fishman (1991). Therefore, interpretation of Brushy Basin deposition in a large lake ("Lake T'oo'dichi") remains unsupported (Anderson and Lucas, 1997).

3. The regional stratigraphic relationships of the Jackpile Member are uncertain. The possibility that it is a Lower Cretaceous unit equivalent to the "Burro Canyon" (=Cedar Mountain) Formation to the north merits further investigation.

#### Eolian Lithofacies

South of Interstate Highway 40, and best displayed at Zuni Pueblo, the Todilto, Summerville and Morrison formations thin and disappear (pinch out or are truncated), and the Jurassic section becomes an unbroken succession of eolianites about 150 m thick (Fig. 7). We refer to this succession as the Zuni Sandstone, following Anderson (1993) and Anderson and Lucas (1994).

At Dowa Yalaane (Taaiyalone), near Zuni Pueblo, which is the type section of the Zuni Sandstone (Dutton, 1885; Anderson, 1983, 1993; Lucas, 2003), the Zuni Sandstone can be divided into three units (Figs. 7-8). The lower ~80 m is eolian sandstone equivalent to the Entrada Sandstone to the north. A prominent notch (break) in the sandstone above that interval is the unconformity surface that marks the pinchout/truncation of the Todilto Formation and at least part (or all?) of the Summerville Formation. The eolian sandstone above the notch, ~60 m thick, is equivalent to the main body of the Bluff Sandstone. The surface above the Bluff interval represents the pinchout/truncation of the Recapture Member of the Bluff Sandstone. The eolian sandstone above that is the Acoma Tongue of the Zuni Sandstone of Anderson (1993). The surface above the Acoma Tongue is the pinchout/truncation of the Morrison Formation and is overlain by the Cretaceous Dakota Sandstone (Figs. 7-8).

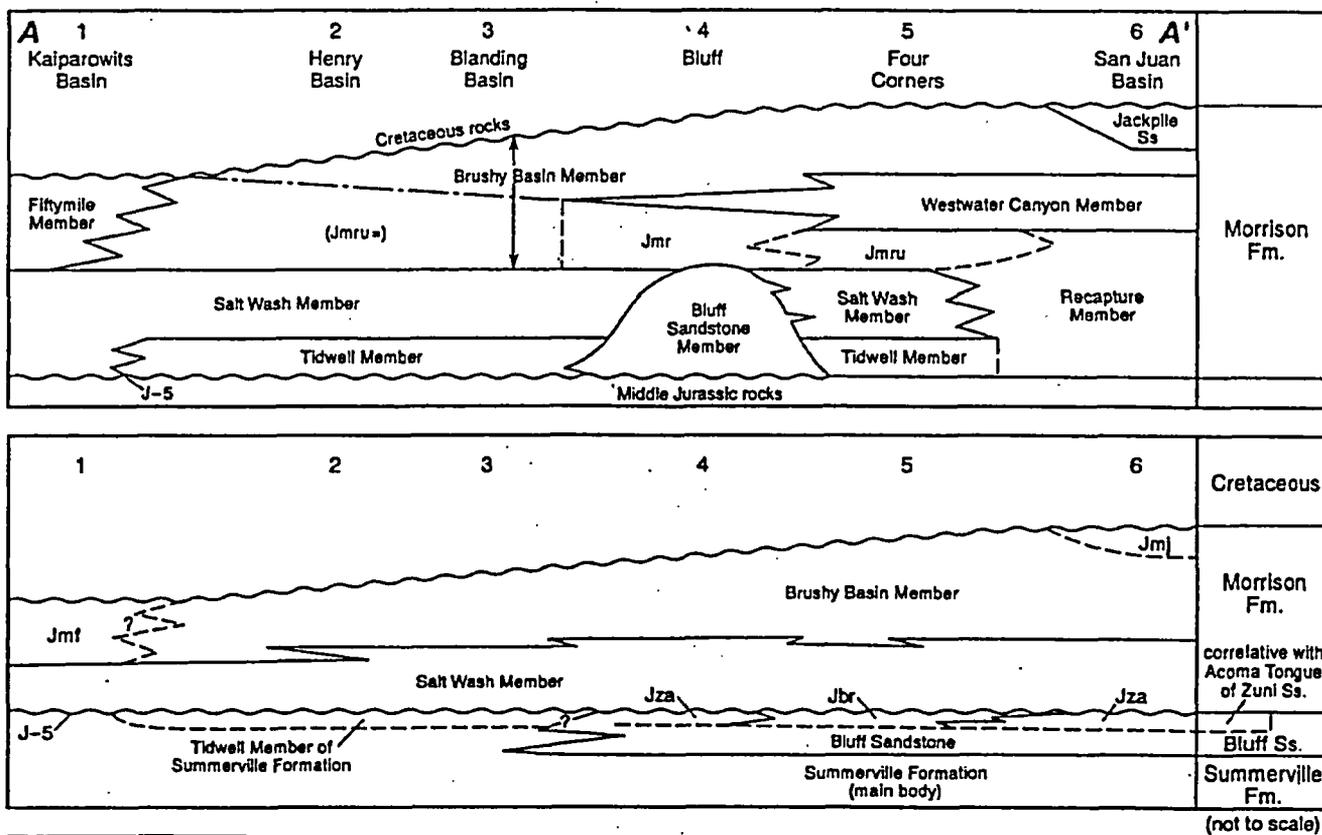


FIGURE 6. Contrast between stratigraphy and correlation of some Middle and Upper Jurassic rocks from Four Corners to west-central New Mexico as envisioned by U.S. Geological Survey (above) and as advocated here (below). After Anderson and Lucas (1997).

The southern edge of the water-deposited lithofacies belt in west-central New Mexico swings northward in eastern Arizona (McKee et al., 1956). Thus, the eolian lithofacies belt accounts for most of the outcrop area of the Middle-Upper Jurassic section in northeastern Arizona. The type section of the Cow Springs Sandstone of Harshbarger et al. (1957) in Arizona is in the eolian lithofacies belt. Strictly speaking, Cow Springs Sandstone, named by Harshbarger et al. (1957) for the unbroken succession of Jurassic eolian sandstones at Cow Springs, Arizona, is a synonym of Zuni Sandstone. However, the name has also been widely misapplied in New Mexico, mostly as a synonym of the Bluff Sandstone (see above).

**SEQUENCE STRATIGRAPHY**

Sound lithostratigraphy is parsimonious. It uses a minimum of names--only those necessary to denominate mappable lithologic units (formations) and their unambiguous subdivisions (members). Only a single name is needed for each lithosome. Formation (and group) boundaries are at surfaces of lithologic contrast, and chronostratigraphic (time) boundaries are not confused with lithostratigraphic boundaries. Physical stratigraphic evidence (e.g., lithologic changes, stratal geometry, presence/absence of subjacent strata) is used to identify unconformities, and they are assigned a time value based on chronostratigraphy. The lithostratigraphy of Jurassic strata in west-central New Mexico

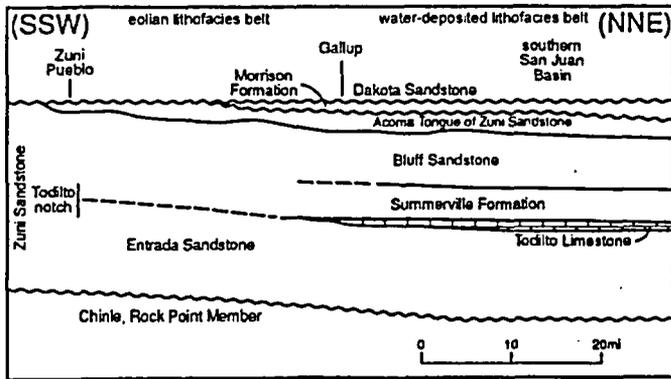


FIGURE 7. Jurassic stratigraphic relationships between the water-deposited and eolian lithofacies belts in west-central New Mexico (after Anderson and Lucas, 1994).

advocated here is just such a parsimonious lithostratigraphy and was so developed by Anderson and Lucas (1992, 1994, 1995, 1996, 1997, 1998) and Lucas and Anderson (1997, 1998).

This lithostratigraphy forms a sound basis for understanding regional Jurassic sequence stratigraphy in west-central New Mexico (Fig. 9). Piringos and O'Sullivan (1978) proposed a succession of Jurassic unconformities that delimit sequences throughout part or all of the Jurassic Western Interior basin. Four of these regional unconformities can be identified in west-central New Mexico's Jurassic section.

The J-2 unconformity separates Middle Jurassic strata of the Entrada Sandstone from underlying Upper Triassic strata of the Wingate Sandstone and Chinle Group. This striking unconformity is unambiguously identified across all of the Jurassic outcrop belt in west-central New Mexico.

The J-3 unconformity of Piringos and O'Sullivan (1978) is the basal transgressive unconformity that separates the Entrada Sandstone from the overlying Curtis Formation. We correlate the Curtis with the Todilto, which suggests that the Todilto base is the J-3 unconformity. Indeed, local stratigraphic relief, rip-up clasts and floating pebbles, as well as sharp lithologic contrast--kerogenic limestone on eolianite sandstone--suggest the base of the Todilto Formation is the J-3 unconformity.

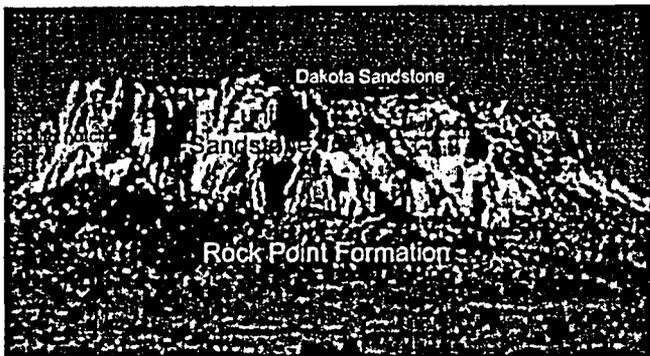


FIGURE 8. Type section of the Zuni Sandstone at Dowa Yalaane near Zuni Pueblo.

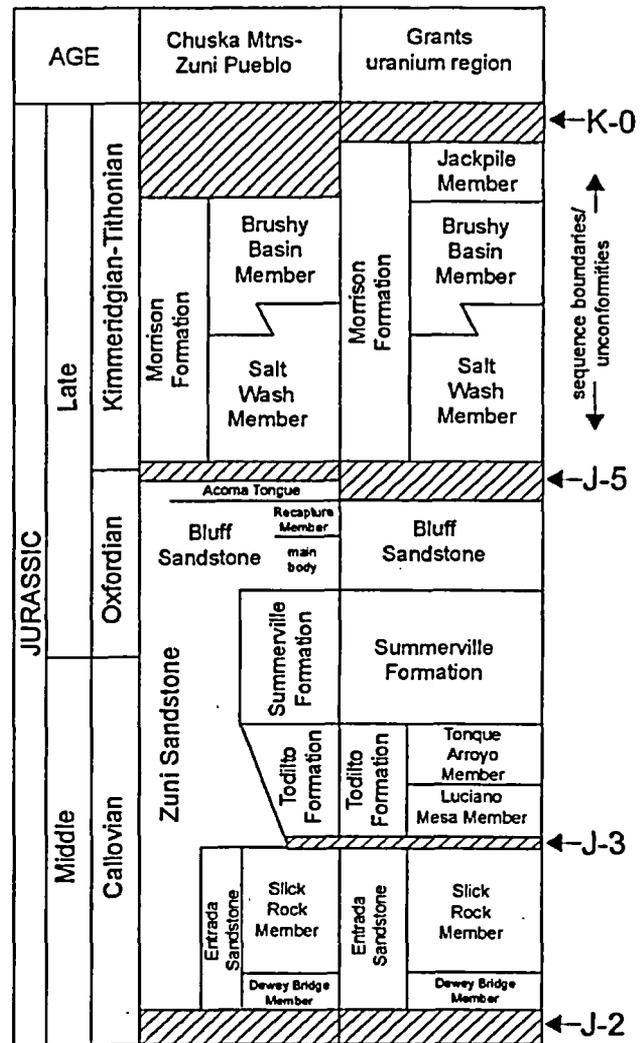


FIGURE 9. Jurassic sequence stratigraphy in west-central New Mexico.

The base of the Morrison Formation was identified by Piringos and O'Sullivan (1978) as the J-5 unconformity. We recognize this unconformity at the base of the Salt Wash Member across west-central New Mexico. The K-0 unconformity of Piringos and O'Sullivan (1978) separates Cretaceous strata (Dakota Sandstone) from underlying Jurassic strata across west-central New Mexico.

ACKNOWLEDGMENTS

We dedicate this paper to Orin Anderson, whose mapping and field studies greatly furthered understanding of Jurassic stratigraphy in the southern Western Interior and made this paper possible. We are also grateful to the late Charles Maxwell, who was a much understated but remarkably perceptive student of Jurassic stratigraphy. Adrian Hunt and Kate Zeigler reviewed the manuscript.

## REFERENCES

- Ahmed Benan, C. A. and Kocurek, G., 2000, Catastrophic flooding of an aeolian dune field: Jurassic Entrada and Todilto formations, Ghost Ranch, New Mexico, USA: *Sedimentology*, v. 47, p. 1069-1080.
- Allen, J. E. and Balk, R., 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 36, 192 p.
- Anderson, O. J., 1983, Preliminary report on redefinition of Zuni Sandstone, west-central New Mexico: *New Mexico Geology*, v. 5, p. 56-59.
- Anderson, O. J., 1993, Zuni Sandstone and Acoma Tongue defined: *New Mexico Geology*, v. 15, p. 38-39.
- Anderson, O. J. and Lucas, S. G., 1992, The Middle Jurassic Summerville Formation, northern New Mexico: *New Mexico Geology*, v. 14, p. 79-92.
- Anderson, O. J. and Lucas, S. G., 1994, Middle Jurassic stratigraphy, sedimentation and paleogeography in the southern Colorado Plateau and southern High Plains; in Caputo, M. V., Peterson, J. A. and Franczyk, K. J., eds., *Mesozoic systems of the Rocky Mountain region, USA*: Denver, RMS-SEPM, p. 299-314.
- Anderson, O. J. and Lucas, S. G., 1995, Base of the Morrison Formation, Jurassic, of northwestern New Mexico and adjacent areas: *New Mexico Geology*, v. 17, p. 44-53.
- Anderson, O. J. and Lucas, S. G., 1996, Stratigraphy and depositional environments of Middle and Upper Jurassic rocks, southeastern San Juan Basin, New Mexico: *New Mexico Geological Society, Guidebook 47*, p. 205-210.
- Anderson, O. J. and Lucas, S. G., 1997, The Upper Jurassic Morrison Formation in the Four Corners region: *New Mexico Geological Society, Guidebook 48*, p. 139-155.
- Anderson, O. J. and Lucas, S. G., 1998, Redefinition of Morrison Formation (Upper Jurassic) and related San Rafael Group strata, southwestern U. S.: *Modern Geology*, v. 22, p. 39-69.
- Anderson, R. Y. and Kirkland, D. W., 1960, Origin, varves and cycles of Jurassic Todilto Formation: *American Association of Petroleum Geologists Bulletin*, v. 44, p. 37-52.
- Armstrong, A. K., 1995, Facies, diagenesis and mineralogy of the Jurassic Todilto Limestone Member, Grants Uranium district, New Mexico: *New Mexico Bureau of Mines and Mineral Resources, Bulletin 153*, 41 p.
- Baker, A. A., Dane, C. H. and Reeside, J. B. Jr., 1936, Correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: *U.S. Geological Survey Professional Paper 183*, 66 p.
- Baker, A. A., Dane, C. H. and Reeside, J. B. Jr., 1947, Revised correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: *American Association of Petroleum Geologists Bulletin*, v. 31, p. 1664-1668.
- Burbank, W. S., 1930, Revision of geologic structure and stratigraphy in the Ouray district of Colorado and its bearing on ore deposition: *Colorado scientific society Proceedings*, v. 12, no. 6, 231 p.
- Condon, S. M., 1989, Modifications to Middle and Upper Jurassic nomenclature in the southeastern San Juan Basin, New Mexico: *New Mexico Geological Society, Guidebook 40*, p. 231-238.
- Condon, S. M. and Peterson, F., 1986, Stratigraphy of Middle and Upper Jurassic rocks of the San Juan Basin: Historical perspective, current ideas, and remaining problems: *AAPG Studies in Geology*, no. 22, p. 7-26.
- Cooley, M. E., Harshbarger, J. W., Akers, J. P. and Hardt, W. F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: *USGS Professional Paper 521-A*, 61 p.
- Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico: Washington, D. C., U. S. Geological Survey, scale 1:500,000.
- Darton, N. H., 1928a, "Red beds" and associated formations in New Mexico, with an outline of the geology of the state: *U. S. Geological Survey, Bulletin 794*, 356 p.
- Darton, N. H., 1928b, Geologic map of New Mexico: Washington, D. C., U. S. Geological Survey, scale 1:500,000.
- Dobrovolsky, E., Summerson, C. H. and Bates, R. L., 1946, Geology of northwestern Quay County, New Mexico: *U.S. Geological Survey Oil and Gas Investigations Preliminary Map 62*.
- Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau: *U. S. Geological Survey, 6<sup>th</sup> Annual Report*, p. 105-198.
- Gilluly, J. and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: *U.S. Geological Survey, Professional Paper 150*, p. 61-84.
- Green, M. W., 1974, The Iyanbito Member (a new stratigraphic unit) of the Jurassic Entrada Sandstone, Gallup-Grants area, New Mexico: *U.S. Geological Survey Bulletin 1395-D*, p. D1-D12.
- Green, M. W., 1981, Origin of intraformational folds in Jurassic Todilto Limestone, Ambrosia Lake uranium mining district, McKinley County, New Mexico: *American association of Petroleum Geologists Bulletin*, v. 65, p. 560.
- Green, M. W., 1982, Origin of intraformational folds in the Jurassic Todilto Limestone, Ambrosia Lake uranium mining district, McKinley and Valencia Counties, New Mexico: *U. S. Geological Survey, Open-file Report 82-69*, 26 p.
- Gregory, H. E., 1917, *Geology of the Navajo Country*: U. S. Geological Survey, Professional Paper 93, 161 p.
- Gregory, H. E., 1938, *The San Juan Country*: U.S. Geological Survey, Professional Paper 188, 123 p.
- Harshbarger, J. W., Repenning, C. A. and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and Jurassic rocks of the Navajo country: *U. S. Geological Survey, Professional Paper 291*, 74 p.
- Heaton, R. L., 1939, Contribution to Jurassic stratigraphy of Rocky Mountain region: *American Association of Petroleum Geologists Bulletin*, v. 23, p. 1153-1177.
- Heckert, A. B. and Lucas, S. G., 1998, The "type" Wingate Sandstone (Upper Triassic-Lower Jurassic) and the homotaxial Entrada sandstone (Middle Jurassic): Resolving stratigraphic problems on the southern Colorado Plateau: *New Mexico Geology*, v. 20, p. 54.
- Kirkland, D. W., Denison, R. E. and Evans, R., 1995, Middle Jurassic Todilto Formation of northern New Mexico and southwestern Colorado: marine or nonmarine?: *New Mexico Bureau of Mines and Mineral Resources, Bulletin 147*, 37 p.
- Lucas, S. G., 2001, The first geologic map of New Mexico: *New Mexico Geology*, v. 23, p. 84-88.
- Lucas, S. G., 2003, Clarence Dutton's stratigraphy of west-central New Mexico: *New Mexico Geological Society, Guidebook 54*.
- Lucas, S. G. and Anderson, O. J., 1996, The Middle Jurassic Todilto salina basin, American Southwest: *Museum of Northern Arizona, Bulletin 60*, p. 479-482.
- Lucas, S. G. and Anderson, O. J., 1997, The Jurassic San Rafael Group, Four Corners region: *New Mexico Geological Society, Guidebook 48*, p. 115-132.
- Lucas, S. G. and Anderson, O. J., 1998, Jurassic stratigraphy and correlation in New Mexico: *New Mexico Geology*, v. 20, p. 97-104.
- Lucas, S. G. and Woodward, L. A., 2001, Jurassic strata in east-central New Mexico and their regional significance: *New Mexico Geological Society, Guidebook 52*, p. 203-212.
- Lucas, S. G., Anderson, O. J. and Pigman, C., 1995, Jurassic stratigraphy in the Hagan basin, north-central New Mexico: *New Mexico Geological Society, Guidebook 46*, p. 247-255.
- Lucas, S. G., Estep, J. W. and Anderson, O. J., 1999, Correlation of Jurassic strata from the Colorado Plateau to the High Plains, across the Rio Grande rift, north-central New Mexico: *New Mexico Geological Society, Guidebook 50*, p. 317-326.
- Lucas, S. G., Heckert, A. B. and Anderson, O. J., 2001, The Middle Jurassic Entrada Sandstone near Gallup, New Mexico: Discussion: *The Mountain Geologist*, v. 38, p. 225-227.
- Lucas, S. G., Heckert, A. B. and Berglof, W. A., 2003, Lectostratotype section of the Jurassic Todilto Formation, western New Mexico: *New Mexico Geological Society, Guidebook 54*.
- Lucas, S. G., Kietzke, K. K. and Hunt, A. P., 1985, The Jurassic System in east-central New Mexico: *New Mexico Geological Society, Guidebook 36*, p. 213-243.
- Lucas, S. G., Rinehart, L. F. and Estep, J. W., 2000, Paleocological significance of Middle Jurassic insect locality, Todilto Formation, north-central New Mexico: *New Mexico Museum of Natural History and Science, Bulletin 16*, p. 41-44.
- Lucas, S. G., Heckert, A. B., Estep, J. W. and Anderson, O. J., 1997, Stratigraphy of the Upper Triassic Chinle Group, Four Corners region: *New Mexico Geological Society, Guidebook 48*, p. 81-107.
- Lupton, C. T., 1914, Oil and gas near Green River, Grand County, Utah: *U. S. Geological Survey, Bulletin 541*, p. 115-133.
- Marcou, J., 1858, *Geology of North America*, with two reports on the prairies of Arkansas and Texas, the Rocky Mountains of New Mexico, and the Sierra Nevada of California, originally made for the United States government.

- Zurich, Zürcher and Furrer, 144 p.
- McKee, E.D., Oriol, S.S., Swanson, V.E., MacLachlan, M.E., MacLachlan, J.C., Ketner, K.B., Goldsmith, J.W., Bell, R.V., Jameson, D.J., and Imlay, R.W., 1956, Paleotectonic maps of the Jurassic System: U.S. Geological Survey, Miscellaneous Investigations Map I-175, scale 1:5,000,000.
- O'Sullivan, R. B., 1980, Stratigraphic sections of Middle Jurassic San Rafael Group from Wilson Arch to Bluff in southeastern Utah: USGS Oil and Gas Investigations Chart OC-102.
- O'Sullivan, R. B., 1996, A comparison of the Middle Jurassic San Rafael Group at Church Rock and at Bluff in southeastern Utah: Utah Geological Association Guidebook 25 (Geology and Resources of the Paradox Basin), p. 191-196.
- O'Sullivan, R. B., 2003, The Middle Jurassic Entrada Sandstone in northeastern Arizona and adjacent areas: New Mexico Geological Society, Guidebook 54.
- Owen, D. E., Walters, L. J., Jr. and Beck, R. G., 1984, The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico—a formal definition: *New Mexico Geology*, v. 6, p. 45-52.
- Pipiringos, G. N. and O'Sullivan, R. B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior, U.S.: A preliminary survey: U.S. Geological Survey, Professional Paper 1035-A, 29 p.
- Rapaport, I., Hadfield, J. P. and Olsen, R. H., 1952, Jurassic rocks of the zuni uplift, New Mexico: U. S. Atomic Energy Commission, RMO-642, 49 p.
- Robertson, J. F. and O'Sullivan, R. B., 2001, The Middle Jurassic Entrada Sandstone near Gallup, New Mexico: *The Mountain Geologist*, v. 38, p. 53-69.
- Smith, C. T., 1954, Geology of the Thoreau quadrangle, McKinley and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 31, 36 p.
- Turner, C. E. and Fishman, N. S., 1991, Jurassic Lake T'oo'dichi': A large alkaline, saline lake, Morrison Formation, eastern Colorado Plateau: *Geological Society of America Bulletin*, v. 103, p. 538-558.
- Weir, G. W. and C. L. Dodson, 1958, Preliminary geologic map of the Mount Peale 3 SE quadrangle, San Juan County, Utah: USGS Map MF-147, scale 1:24,000.
- Wright, J. C., D. R. Shawe, and S. W. Lohman, 1962, Definition of members of Jurassic Entrada Sandstone in east-central Utah and west-central Colorado: *AAPG Bulletin*, v. 46, p. 2057-2070.
- crossbeds; uncommon ripple laminations; slightly calcareous. 3.4
- unconformity (J-2 unconformity of Pipiringos and O'Sullivan, 1978):
- Glen Canyon Group:**
- Wingate Sandstone (type "Iyanbito member" of Green, 1974):**  
(The base of unit 25 seeps down into cracks and fissure fills as much as 0.3 m into unit 24, as shown below.)
- 25/24 Mottled, probably originally pale reddish brown (10R5/4) fading into yellowish gray (5Y8/1) and bluish gray (5B9/1); fine- to medium grained, locally coarser, subrounded, moderately sorted quartzarenite; calcareous.
- 24 Sandstone; bluish white (5B9/1) with moderate reddish orange (10R6/6) mottles; fine-grained, subrounded-subangular, moderately sorted quartzarenite (eolianite); trough crossbedded; calcareous. 0.8
- 23 Sandstone; moderate reddish orange (10R6/6); very fine-grained, subrounded, moderately well-sorted quartzarenite; some faint crossbeds—more prominent than underlying unit; calcareous. 1.6
- 22 Sandstone; pale reddish brown (10R5/4); very fine- to fine-grained, subrounded moderately well-sorted quartzarenite; locally medium-grained; hackly; slightly silty; weakly calcareous. 1.2
- 21 Sandstone; light greenish gray (5GY8/1) fresh; weathers moderate orange pink (10R7/4); very fine- to medium-grained, subrounded to rounded, moderately sorted quartzarenite; silty; trough crossbedded; calcareous. 0.2
- 20 Sandstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4); very fine- to fine-grained, subangular to subrounded, moderately well-sorted quartzarenite; locally coarser-grained; trough crossbedded, not calcareous. 4.3
- 19 Shale parting; same colors and lithologies as unit 17. 0.01
- 18 Sandstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4); fine- to medium-grained, subrounded, poorly sorted quartzarenite; some black and white very coarse-grained-pebbly clasts of clay and chert; trough crossbedded; weakly indurated; calcareous. 1.8
- 17 Shale parting; grayish brown (5YR3/2); slightly silty; not calcareous. 0.01
- 16 Sandstone; pale red (10R6/2) to moderate reddish orange (10R6/6); very fine-grained, subrounded, moderately well-sorted quartzarenite; laminar; not calcareous. 2.2
- 15 Sandstone; same colors and lithologies as unit 13; ripply. 2.3
- 14 Sandstone; same colors and lithologies as unit 3; laminar in 0.5-m-thick tabular sets with partings like 13. 2.3
- 13 Sandstone; moderate reddish orange (10R6/6) with grayish orange pink (10R8/2) spots; very fine- to fine-grained, subangular to subrounded, moderately sorted quartzarenite; silty to medium-grained locally; ripply; bioturbated; calcareous. 0.7
- 12 Sandstone; same colors and lithologies as unit 10. 3.0
- 11 Sandstone; same colors and lithologies as unit 7; white trough crossbeds. 0.6
- 10 Sandstone; moderate orange pink (10R7/4) to moderate reddish orange (10R6/6); very fine- to coarse-grained, angular to rounded, very poorly sorted quartzarenite; some white (N9) sand-sized clay rip-ups; trough crossbedded; coarse grains on foresets; calcareous. 3.0
- 9 Sandstone; moderate reddish orange (10R6/6); very fine- to fine-grained, subangular-subrounded, moderately well-sorted quartzarenite; bioturbated; silty; some mottling to light greenish gray (5GY8/1); calcareous. 1.0
- 8 Sandstone; moderate reddish orange (10R6/6) trending toward pale reddish brown (10R5/5); very fine- to fine-grained, subrounded, moderately sorted quartzarenite (eolianite); trough-crossbedded; calcareous. 1.1
- 7 Sandstone; very pale blue (5B8/2) fresh, weathers to light brownish gray (5YR6/1) very coarse- to coarse-grained, well rounded, moderately well-sorted sublitharenite; most lithics are clay and chert; very calcareous. 0.3
- 6 Sandstone; same colors and lithologies as unit 2. 1.7
- 5 Sandstone; pale reddish brown (10R5/4) fresh; weathers to moderate reddish brown (10R4/6); subrounded, fine-grained, well-sorted quartzarenite; laminar; not calcareous. 0.6

#### APPENDIX 1: MEASURED SECTION OF TYPE "IYANBITO MEMBER"

Section measured in the NW1/4 sec. 15, T15N, R16W, McKinley County, New Mexico, at the same location as Green's (1974) type section.

unit	lithology	thickness (m)
<b>Entrada Sandstone:</b>		
<b>Slick Rock Member:</b>		
29	Sandstone; pale red (10R6/2) and pale reddish brown (10R5/4), locally bleached pinkish gray (5YR8/1) to bluish white (5B9/1); very fine-grained, subangular quartzarenite (eolianite); trough crossbedded; weakly calcareous.	not measured
<b>Dewey Bridge Member:</b>		
28	Sandstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4); some spots of grayish orange pink (10R8/2); fine-grained, subangular to subrounded, silty quartzarenite (eolianite); trough crossbedded with some sets of ripple laminations; not calcareous.	0.7
27	Sandstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4); some spots of grayish orange pink (10R8/2); fine-grained, subangular to subrounded, silty quartzarenite (eolianite); slightly more indurated than overlying unit; ripple laminated to flaser bedded; not calcareous.	0.9
26	Sandstone; pale red (10R6/2) to pale reddish brown (10R5/6) very fine-grained, subangular to subrounded, slightly silty quartzarenite; faint trough crossbeds and more ripple lamination than underlying unit; weakly calcareous.	3.3
25	Sandstone; moderate reddish orange (10R6/6) to pale reddish brown (10R5/4); very fine- to fine-grained, subrounded, moderately well-sorted quartzarenite; slightly silty; faint trough	

4	Shale parting; dark reddish brown (10R3/4); silty; = unit 3 of Green (1974); not calcareous.	0.02
3	Sandstone; moderate reddish orange (10R6/6) to grayish red (10R4/2); very fine- to fine-grained, subangular, moderately well-sorted quartzarenite; slightly silty; trough crossbeds; white (N9) coarse grains to pebbles of chert and claystones on foresets; not calcareous.	10.8
2	Sandstone; white (N9), mottled as dark as pale reddish brown (10R5/4); stringers of very coarse-grained to pebbly rounded chert; otherwise fine-grained, subrounded, moderately well-sorted quartzarenite; fills dikes, cracks, and fissures in underlying Owl Rock Formation, as Green (1974) describes; not calcareous.	0.2-0.3
unconformity (Tr-5 unconformity of Lucas, 1993)		
<b>Chinle Group:</b>		
<b>Owl Rock Formation:</b>		
1	Sandstone; mottled grayish red purple (5RP4/2); white (N9) and light greenish gray (5G8/1); fine- to medium-grained, subangular, moderately poorly sorted muddy litharenite; well-indurated; bioturbated; disrupted bedding; not calcareous.	not measured

**APPENDIX 2: SECTION LOCATIONS**

Map coordinates of the measured sections in Figure 3 are listed here.

Type Dewey Bridge: UTM zone 12, 646109E, 4297255N (sec. 8, T23S, R24E, UT).

Type Slick Rock: UTM zone 12, 683084E, 4211885N (sec. 36, T4N, R19W, CO).

Mexican Water: base at UTM zone 12, 625266E, 4095280N, top at UTM zone 12, 625495E, 4095921N (near Mexican Water, AZ).

Lohali Point: at UTM zone 12, 607891E, 3997107N (sec. 6, T31N, R24E, Apache County, AZ).

Wagon Wheel: at UTM zone 12, 663754E, 4035290N (sec. 12, T35N, R29E, Apache County, AZ).

White Cone: at UTM zone 12, 676363E, 4012496N (San Juan County, NM).

Little White Cone: at UTM zone 12, 678853E, 3997612N (sec. 31, T22N, R21W, San Juan County, NM).

Todilto Park: at UTM zone 12, 684992E, 3982776N (San Juan County, NM).

Lupton: at UTM zone 12, 676609E, 3911625N (near Lupton, Arizona)

Red Rocks: SE ¼ sec. 11, T15N, R17W, McKinley County, NM.

Type Iyanbito: NW ¼ sec. 15, T15N, R16W, McKinley County, NM.

Thoreau: at UTM zone 12, 759120E, 3924300N (Cibola County, NM).

Mesa Montañosa: at UTM zone 13, 240940E, 3911731N (Cibola County, NM).

# EXHIBIT F

**THE LARGE-SCALE ARCHITECTURE OF THE FLUVIAL WESTWATER CANYON MEMBER, MORRISON FORMATION (UPPER JURASSIC), SAN JUAN BASIN, NEW MEXICO**

E. JUN COWAN  
Department of Geology,  
University of Toronto,  
Toronto, Ontario, Canada M5S 3B1

**ABSTRACT:** The Westwater Canyon Member of the Morrison Formation (Upper Jurassic) has previously been interpreted as consisting of fluvial "channel systems" (sets of channelized beds and sets of meandering belts). Reinterpretation of the member indicates that three "channel systems" actually represent post-depositional scoured channels, defined by different sandstone colors, rather than primary depositional features. The member is composed of amalgamated, laterally fining-up sandstone sheets with about 5-10 m thick. The abundant widths of these sandstone bodies are at least 1 km and possibly exceed several kilometers. The width-to-thickness ratio of the sandstone sheets are well within the typical values of sandstone body dimensions reported from other fluvial sandstones, and are interpreted to represent aggradational channel-belt. Sandstone bodies thicker than about 12 m are the result of amalgamation of these individual unit sandstone bodies, and do not represent individual channel belts as interpreted previously.

Initially, the sheet contains abundant concave-up troughs typically 30 m wide and 5 m deep, filled both laterally and vertically with inclined parallel- to low-angle cross-stratified sandstone, in places exhibiting parting lamination. The locally limited extent of these large troughs and nature of their internal fill suggest that they represent short-lived scour fills rather than confined elongated channels. The concave-up erosional base, a negative feature, was most likely formed due to large-scale flow separation within a wider and shallower channel. Physical conditions similar to storm flow overtopping at channel confluences may be responsible for their formation. The abundant preservation of these troughs in the Westwater Canyon Member is consistent with the supposed poor preservation of positive bedforms in a sweeping, sandy-branched channel belt.

Review of the literature indicates that inferred channel-belt sandstone bodies mostly fall within the thickness range of 1 to 12 m, irrespective of their interpreted fluvial style. Post-depositional large-scale reservoir conditions are also expected to fall within this range for sandy fluvial systems. Deviations from this range are due to amalgamation of the sandstone bodies or increased grain-size heterogeneity, resulting in an increase and decrease, respectively, of the channel size.

**INTRODUCTION**

Clarifying the origin and post-depositional burial history of fluvial-sandstone bodies is critical to understanding the scale and role of heterogeneities involved in the migration of pore fluids following the burial of sandy fluvial deposits (cf. Miall, 1988b). The architecture of sandstone bodies resulting from channel-belt avulsion and coval basinal subsidence has been modeled quantitatively by several workers (Alexander and Leeder, 1987; Allen, 1978; Bridges and Leeder, 1979; Leeder, 1978). These quantitative models are able to predict depositional patterns resulting from syndepositional subsidence and repeated avulsion of channel belts. The resulting architecture of the sandstones controls the pore-fluid flow, and hence influences hydrocarbon migration and the emplacement of some economic metalliciferous ores, such as uranium. Application of these models requires the field recognition of individual channel-belt deposits. There are, however, few field descriptions in the fluvial literature, especially those of sandy multichannel fluvial systems, which

differentiate individual channel belts from laterally and vertically interconnected channel-belt deposits.

One of the best-known examples of the documentation of alluvial architecture is that of Campbell (1976) on the Upper Jurassic Westwater Canyon Member of the Morrison Formation, San Juan Basin, New Mexico. Campbell's work has been extensively cited as a typical example of a braided river deposit involving the preservation of laterally coalesced "channel systems" and "smaller channels" and has been repeatedly used in textbooks (e.g., Cant, 1978; Leeder, 1981; Collinson, 1986). These "channel systems" were described by Campbell (1976) to be vertically and laterally coalesced, and to range in width from 1.6 to 34 km and in thickness from 6 to 61 m. Individual "smaller channels" have widths of 30 to 366 m and depths from 1 to 6 m (Campbell, 1976).

On the basis of detailed outcrop studies, this paper shows that the "channel systems" of Campbell (1976) do not represent depositional channels, but are post-depositional aquifer conduits or permeability-pathway compartments. The conduits (identified on the basis of color, which reflect the state of sandstone oxidation) are up to several tens of meters thick, and were formed by the vertical coalescence of sandstone sheets about 5-10 m in thickness, interpreted here to represent channel-belt deposits. The sheets are internally composed of large concave-up features ("smaller channels" of Campbell, 1976) which are interpreted to represent large scour fills produced in a wide braided channel belt.

**GEOLOGICAL OVERVIEW**

The Upper Jurassic Morrison Formation was deposited in the San Juan Basin (Figs. 1a, b) which lay several hundred kilometers east of a Late Jurassic Andean-

type, magmatic arc. The detrital infill is derived from the uplifted edge of the foreland (cf. Turner-Peterson and Fishman, 1986). The Morrison Formation (mean thickness 200 m), famous for hosting more than half the uranium reserves in the United States, is divided into three members in the study area (Fig. 2), which are in ascending order 1. Recapture Member, a lithologically heterogeneous unit comprising intertonguing fluvial, lacustrine and solonch deposits; 2. the Westwater Canyon Member, a laterally extensive fluvial sandstone; and 3. the Brushy Basin Member, a plays lake complex (Turner-Peterson, 1985, 1986; Turner-Peterson and Fishman, 1988). The Westwater Canyon Member underlies and intertongues with the overlying Brushy Basin Member along an arbitrary boundary. The Brushy Basin Member was truncated by late Early Cretaceous erosion during uplift along the southern margin of the San Juan Basin. In the southwestern portion of the basin, the Upper Cretaceous Dakota Sandstone directly overlies the Westwater Canyon Member, whereas toward the east the Brushy Basin Member thickens at the expense of the Westwater Canyon Member.

Clear breaks in the stratigraphy, together with differing pebbles lithologies, were used by Turner-Peterson (1986) to divide the Westwater Canyon fluvial unit into three submembers thought to represent separate fluvial episodes. On the basis of trough cross-stratification orientations, Turner-Peterson (1986) concluded that the lower fluvial unit shows a northeast to east-northeasterly-directed, basin-wide paleoflow pattern, whereas the middle and upper units showed a basin-wide southeast to east-southeasterly-directed pattern. The overlying Poison Canyon Sandstone (a unit belonging to the Brushy Basin Member of the eastern San Juan Basin) and its possible equivalents showed a return to a northeasterly-directed paleoflow. These patterns are quite different from the paleoflow patterns of Campbell (1976), who considered the whole of the member to have been deposited

by a northeasterly-directed fluvial system. The paleoflow directions of Turner-Peterson (1986) show that Campbell's (1976) transect of the fluvial system is subparallel to the regional paleoflow and is not transverse, as Campbell (1976) suggested. Consequently, transverse views of the Westwater fluvial system, as illustrated by Campbell (1976, his Fig. 2, and Fig. 3 herein), are unlikely to represent channel cross sections.

Miall and Turner-Peterson (1989) re-analysed the Westwater Canyon Member utilizing the conceptual six-fold hierarchical subdivision of bounding surfaces (Miall, 1983c). Individual lithologies (cf. Miall, 1978) were identified and separated, then combined into lithofacies assemblages defining "architectural elements" (cf. Miall, 1985). The presence of lateral-accretion deposits along with downstream-accreted macroforms in the same exposures, was interpreted to be the product of sandfill deposition in a low-inosity, multiple-channel river. They could not find support for the fining-upward channel-fill cycles as documented by Campbell (1976). The present study supports the braided channel interpretation of Miall and Turner-Peterson (1989), but many of the structures interpreted to represent lateral/downstream-accretion macroforms are reinterpreted herein as laterally restricted scour fills formed in a wide braided-channel belt. Fining-upward cycles in this unit have now been documented by Godin (1991).

The purpose of this paper is to describe the architecture of the Westwater Canyon Member at two scales. 1. The first deals with the structures at the member scale and describes the largest architectural component of the Westwater Canyon Member, namely 5-10-m-thick sandstone sheets. The identified sheets are contrasted with Campbell's (1976) architectural reconstruction of the member. 2. The second scale of description details the internal architecture of the sheet sandstones identified in part one, as well as the significance of abundant large troughs (typically 30 x 5 m) present in the sheets.

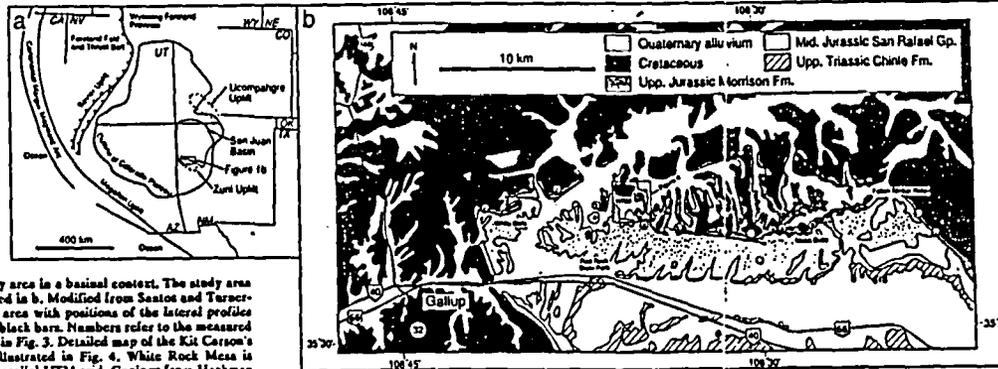


FIG. 1.—a. Location of the study area in a basinal context. The study area enclosed in the rectangle is detailed in b. Modified from Santos and Turner-Peterson (1986, Fig. 3). b. Study area with positions of the lateral profiles used to construct Fig. 6 shown as black bars. Numbers refer to the measured sections of Campbell, also shown in Fig. 3. Detailed map of the Kit Carson's Cave area, shown enclosed, is illustrated in Fig. 4. White Rock Mesa is labeled as "WRM". Map borders parallel UTM grid. Geology from Hackman and Olson (1977).

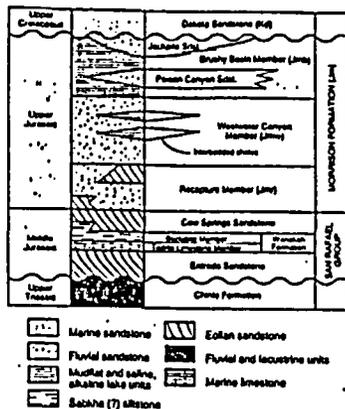


FIG. 2.—Generalized stratigraphy of the Jurassic strata, as exposed in the uplifted edge of the southern San Juan Basin. From Turner-Peterson (1984, Fig. 2)

#### METHODS

The Westwater Canyon Member crops out discontinuously for about 500 km around the west and southern uplifted margins of the San Juan Basin. Photomosaics were produced from oblique aerial and ground photographs along a transect on the east-west-trending cliff forming the southern margin of the basin, exposed in northwest New Mexico (Fig. 1b). These were used as base maps for plotting major surface traces of the lithologic boundaries, both with the aid of binoculars and by walking the outcrop where possible. Four profiles in the Kit Carson's Cave area were examined where the exposure was flat enough to permit inspection on a more detailed level (Fig. 4).

The outcrop shown in Figure 5 illustrates the nature of the Westwater Canyon Member at White Cliffs. The original drawings of similar cliff exposures were redrawn at a vertical exaggeration of five, and each of these profiles was projected into the plane joining Campbell's (1976, his Fig. 2) measured sections 1 and 9 (see Fig. 1b). Campbell's profile (Fig. 3) was also redrawn to match the 25 vertical

exaggeration of the profile presented here to enable direct visual comparison (Fig. 6). Sandstone color was noted and divided into three broad categories; white, buff and red.

The descriptive terminology of sandstone bodies used here follows that of Friend and others (1979) who introduced a classification scheme based on the width:thickness ratio of sandstone bodies. Sandstones with width:thickness ratios less than 15:1 are termed ribbon-sandstone bodies, and sandstone bodies that have width:thickness ratios of over 15:1 are termed sheet-sandstone bodies. The sandstone bodies of the Westwater Canyon Member all display ratios greatly exceeding 15 and are therefore idealized as sheet sandstones.

The lithofacies scheme follows that of Miall (1978) with modifications (Table 1). Lithofacies within the sandstone sheets include horizontal and parallel upper-flow-regime stratification (Sh), inclined and parallel upper- to transitional-flow-regime stratification (Si), low-angle cross-stratified ( $<10^\circ$ ) upper- to transitional-flow-regime stratification (Sj), trough cross-stratification representing lower-flow-regime three-dimensional dunes (Sd), topset-preserved cover-up hummock cross-stratification (Sbb) and rare climbing ripple cross-lamination (Sr), which was identified at only one location. Lithofacies Si essentially represents lithofacies Sh

that formed on an inclined surface (see Paola and others, 1989, their Fig. 2). By far the most predominant lithofacies are Si, Sj and Sh which make up more than 80% of the deposit and were difficult to separate because of complex gradations. Another lithofacies, Sbb, although subordinate in occurrence, is interpreted to be the product of deposition from hummock dunes (cf. Sanderson and Lockett, 1983; Allen, 1983a). A more detailed discussion of the gradation between these lithofacies is presented in Cowan (1990) and Godin (1991).

The bounding-surface subdivision employed in the detailed profiles of the Kit Carson's Cave area (Fig. 4) is modified from Miall (1986c). First-order bounding surfaces that bound sets of lithofacies are not illustrated here in all profiles unless indicated. Second-order bounding surfaces are planes that separate coasts of dissimilar lithofacies. In this paper third- and fifth-order bounding surfaces are laterally restricted and extensive, discordant erosional surfaces respectively. Sixth-order bounding surfaces are essentially fifth-order surfaces, but are located between major depositional systems (such as formational boundaries). Third-order bounding surfaces are commonly concave-up in sectional view, and fifth- and sixth-order bounding surfaces are flat across most of the exposures, but may undulate locally. Cover-up fourth-order bounding surfaces, interpreted by Miall (1986c) to

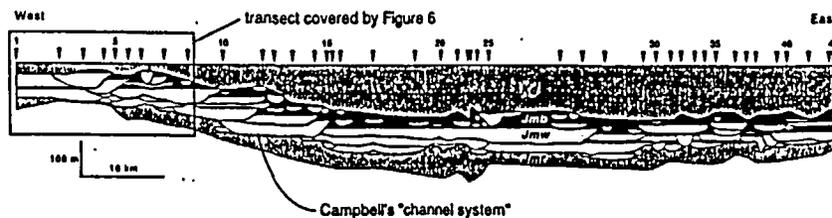


FIG. 3.—Cross section of the Morrison Formation according to Campbell (1976, his Fig. 2). The rectangle represents the re-examined section as presented in this study (Fig. 1b), and illustrated in Fig. 6. Stratigraphic abbreviations are: Recapture Member of the Morrison Formation (Jmr), Westwater Canyon Member (Jwm), Brushy Basin Member (Jwb), Dakota Sandstone (Kd). Numbers refer to the measured sections of Campbell (1976). Vertical exaggeration is  $\times 25$ . The upper surface of Kd is not the actual top of the Dakota Sandstone.

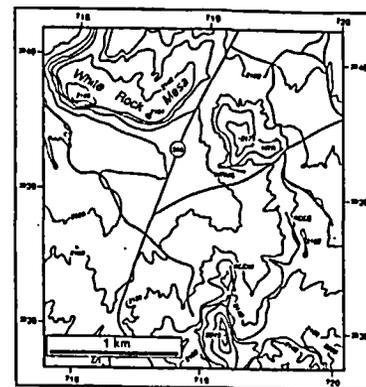


FIG. 4.—The Kit Carson's Cave area in detail. Contours in 20-m intervals. Location of detailed lateral profiles (Figs. 7, 10, 13 and 16) labeled: White Rock Mesa East (WRME), Hill Top Road (HTR), Kit Carson's Cave East (KCE), Kit Carson's Cave West (KCCW). 1-km UTM grid reference from Church Rock 24,000 topographic sheet.

represent constructional surfaces of macroforms, were not recognized in the study.

#### PART 2: THE LARGE-SCALE SANDSTONE SHEETS OF THE WESTWATER CANYON MEMBER

Of the large-scale profiles, only the White Cliffs profile located on the westernmost end of Campbell's (1976) profile (Fig. 3), is described in detail here. Other profiles are simplified and presented as Figure 6.

##### White Cliffs Profile

At White Cliffs (Fig. 5) the lower basal contact of the Westwater Canyon Member with the underlying Recapture Member is sharp, and can be followed consistently across the exposure. The sixth-order erosional bounding surface between the Westwater Canyon Member and the overlying Dakota Sandstone is also sharp, but attains a relief of several meters just east of the break in the cliff line (Fig. 5). The overlying Dakota Sandstone is a block carbonaceous shale, a

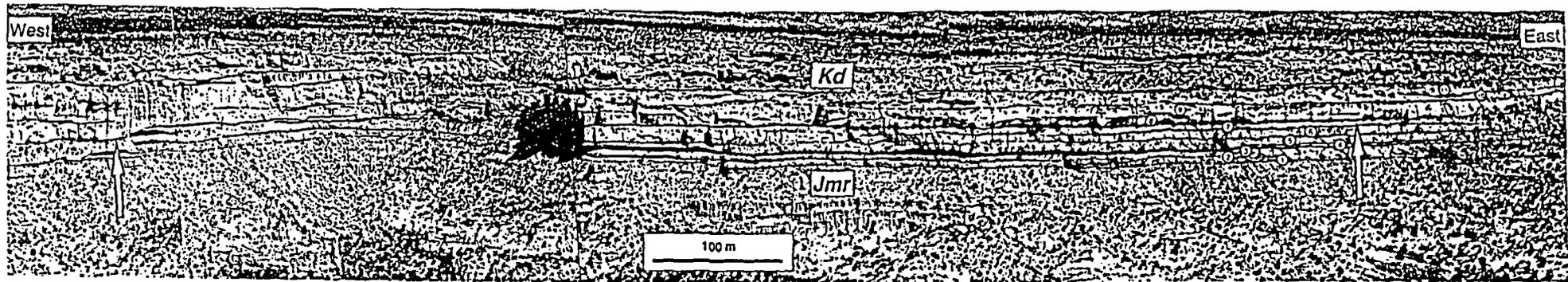


FIG. 5.—An example of a cliff profile from White Cliffs (refer to Fig. 1b for location). Each sheet-sandstone body composing the member is numbered one to eleven on the eastern end of the profile. Note the amalgamating nature of the sandstone sheets toward the

western end of the profile. Vertical sandstone color changes (marked by arrows - see text for explanation) are controlled by the preservation of thick overbank deposits, shown in black.

yellowish sandstone, or interbeds of these two lithologies.

The Westwater Canyon Member at White Cliffs is composed of eleven vertically stacked sandstone sheets, as defined on the eastern portion of the profile; due to extensive amalgamation, the units are not readily seen on the western side. The sheets have flat, erosive bases, except for isolated concave-up erosional bases, which are several tens of meters wide, and display reliefs of 2 to 3 m (Fig. 5). The sheets are 3 m thick and are capped by green/rod/white-colored fine sandstone and subordinate shales which are interpreted to be of fluvial overbank affinity. The basic building blocks of the member are these sandstone-overbank couplet sheets. At White Cliffs, the paleocurrents from trough cross-stratified sets indicate a largely easterly directed paleoflow, that is, to the right and obliquely out of the profile, which trends 252° to 072° (Fig. 5). Sheets are inferred to be tabular in three dimensions, but locally show marked lateral thinning on the scale of the exposure. Sandstone sheet 5, for example, can be followed from east to west where it thickens and becomes interlayered with overbank deposits of the same order of thickness as the sandstone body, indicating proximity to an edge of the sheet. Therefore, the edges of these tabular sandstone sheets are inferred to have a very low-angle wedge shape. In most of the other studied exposures, however, the lateral terminations of the sandstone sheets are not commonly observable, most likely because the cliff faces are orientated subparallel to the easterly directed paleoflow, and as a result, subparallel to the long axes of the sheet sandstones as well.

The overbank deposits can reach thicknesses of up to 3 m at White Cliffs (as can be seen in the center of the profile; Fig. 5), but commonly are thinner, truncated in many places by the overlying sandstone sheet. The lateral variation in color of the sandstone is evident from this exposure (the color boundaries are schematically represented in Fig. 6). The boundary between white- and buff-colored sandstone is located a third of the height up from the base of the Westwater Canyon Member on the western side of the profile, whereas a similar color boundary is located higher up to the east. At both ends of the profile, the vertical color change corresponds to horizons with marked preservation of overbank deposits (all arrows shown in Fig. 5).

#### Composite Lateral Profiles

The lateral extent of the profiles presented in Figure 6 starts at the westernmost portion of Campbell's (1976) transect and follows through to his measured section 9 (Figs. 1b, 3), which represents one fifth of the transect of Campbell (1976). Individual erosional bounding surfaces are difficult to trace entirely along more than 1.5 km of cliff line (Fig. 6). The erosion surfaces are just where the sandstone sheets amalgamate. Amalgamated erosional surfaces can be identified by intricate horizons within the amalgamated unit, but in many cases these horizons are missing. It should be noted that, in general, it is not possible to trace the base of a sandstone

sheet across to adjacent cliff exposures separated by valleys. This is contrary to the documentation of Campbell (1976), in which his westward overstepping pattern of the "channel systems" in the Westwater Canyon Member (Fig. 3) is entirely based on the ability to trace these bounding surfaces laterally for long distances.

The color of the sandstone is highly variable from one cliff exposure to another; however, white alteration is always underlain by reddish-colored sandstone, never the reverse. The boundaries of these color changes are laterally gradational but are vertically abrupt at any one location. They commonly coincide with bases of sheet sandstones where the erosion surface has not truncated the underlying overbank deposit (White Cliffs and White Rock Mesa areas, Fig. 6). White sandstones in places occur completely enclosed in fine-grained overbank deposits in the eastern sections (i.e. in two dimensions, e.g., Mesa Butte, Fig. 6). The lateral variation in color change does not coincide with obvious lateral terminations of the sheet sandstones.

#### Interpretation of the large-scale profiles

The inspection of the sandstone color distribution in the Westwater Canyon Member, as summarized in Figure 6, indicates that the vertical amalgamation of the fluvial sheet sandstones played an important role in controlling the final sandstone color distribution within the Westwater Canyon Member. The origin of

TABLE 1.—The main lithologies of the Westwater Canyon Member, based partly on Miall's (1978) lithofacies codes.

LITHO-FACIES CODE	GRAIN SIZE	CHARACTER AND STRATIFICATION	INTERPRETATION	OCCURRENCE
Sh	fine to very coarse sand	grading between, subhorizontal stratification; closely associated and gradational with S1/S2	upper flow regime; some bedding by subhorizontal set-out, low relief bed forms	common
SUS1	fine to coarse sand	aggradational, partly horizontal, inclined partial stratification (S1), or less than 10 degree angular discontinuity (S2) to the underlying bounding surface. In places appear broad trough traps	lower to transitional flow regime; surface and P part of (1978)	very common
S1	fine to coarse sand; may be pebbly	2-8 m thick sand; commonly occur as sheets; interbedded with S1/S2; colorless granules that S1/S2 or S4	lower flow regime; 3D dunes	fairly common
S1hb	fine to coarse sand; may be pebbly	fine subhorizontal bedding; grade may include of sand, sometimes pebbly lenses; bottom trough shaped in transverse section and somewhat flat (horizontal) top in longitudinal section	transitional flow regime; horizontal dunes or bar forms; see Allen (1973a), Sanderson & Leckie (1983)	subordinate
S1	very fine sandstone	size of A or B type dune; ripple marks; cross lamination	lower flow regime; 3D dunes	rare

Continued on page 81

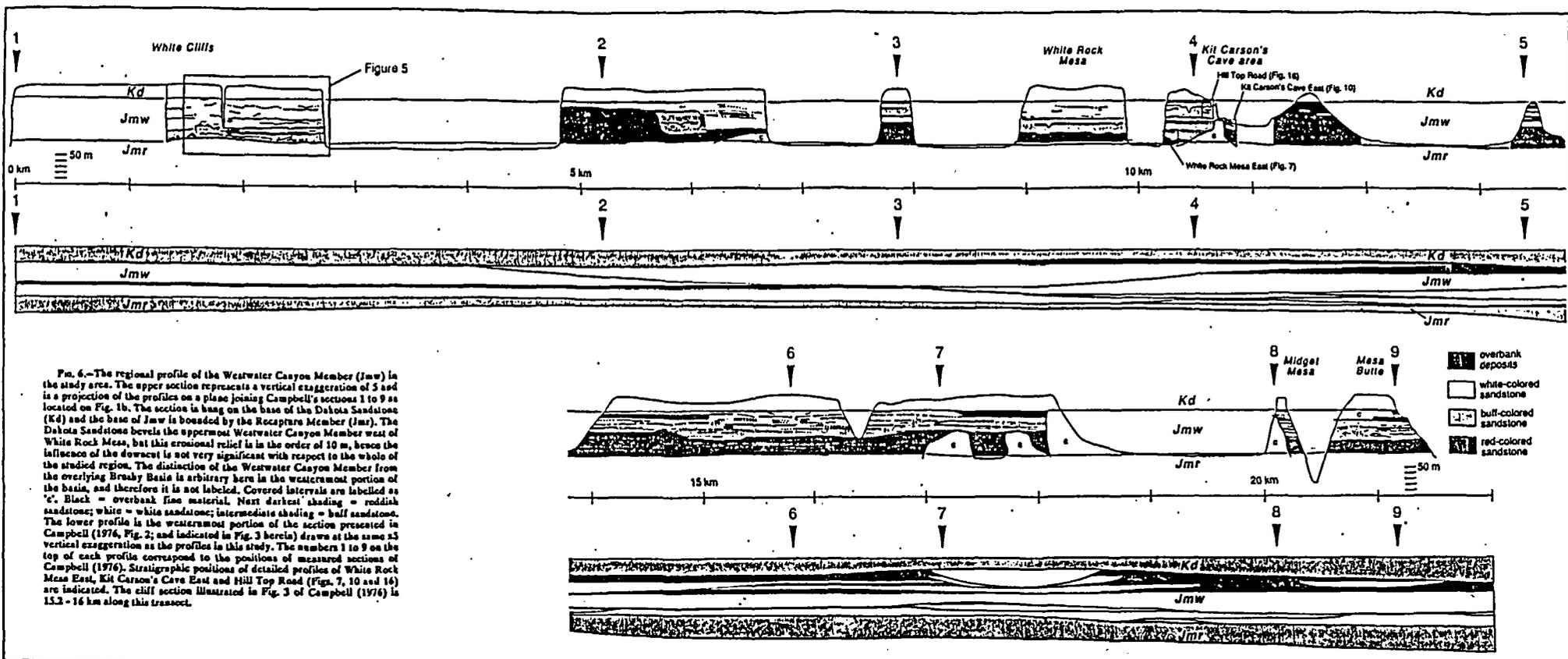


FIG. 6.—The regional profile of the Westwater Canyon Member (Jmw) in the study area. The upper section represents a vertical exaggeration of 5 and is a projection of the profiles on a plane joining Campbell's sections 1 to 9 as located on Fig. 1b. The section is based on the base of the Dakota Sandstone (Kd) and the base of Jmw is bounded by the Recapture Member (Jmr). The Dakota Sandstone overlies the uppermost Westwater Canyon Member west of White Rock Mesa, but this erosional relief is in the order of 10 m, hence the influence of the downdip is not very significant with respect to the whole of the studied region. The distinction of the Westwater Canyon Member from the overlying Breathy Basins is arbitrary here in the westernmost portion of the basin, and therefore it is not labeled. Covered intervals are labeled as 'c'. Black = overbank fine material, Next darkest shading = reddish sandstone; white = white sandstone; intermediate shading = buff sandstone. The lower profile is the westernmost portion of the section presented in Campbell (1976, Fig. 2); and indicated in Fig. 3 hereinafter drawn at the same 1:5 vertical exaggeration as the profiles in this study. The numbers 1 to 9 on the top of each profile correspond to the positions of measured sections of Campbell (1976). Stratigraphic positions of detailed profiles of White Rock Mesa East, Kit Carson's Cave East and Hill Top Road (Figs. 7, 10 and 16) are indicated. The cliff section illustrated in Fig. 3 of Campbell (1976) is 15.2-16 km along this transect.

the various shades of sandstone colors, and their vertical and lateral distributions, can only be understood by examining the diagenetic history of the Westwater Canyon Member, as discussed below.

**Diagenetic history of the Westwater Canyon Member.** The sandstone colors observable in the cliff exposures of the Westwater Canyon Member are the cumulative result of three known diagenetic events that occurred during the Jurassic to Tertiary Periods (see Turner-Peterson, 1983, 1986; Granger and Santos, 1986; Hanaey, 1986). Two episodes of bleaching, resulting in either the reduction or removal of iron from the detrital grains, left some Westwater Canyon Member sandstones either gray or white. The first episode occurred in the Late Jurassic to Early Cretaceous and was related to alkaline, organic-rich fluids, and the second episode occurred in the Late Cretaceous, and was related to acid, organic-rich fluids. The prominent red color of the member represents the third, and most recent coloration, which is linked to a Tertiary oxidation event. These diagenetic events are summarized as follows:

1. The initial alteration, during the Late Jurassic to Early Cretaceous, was caused by organic acids expelled down from the fine-grained sandstone units in the overlying Brushy Basin Member, which reacted with iron-titanium oxides (chiefly magnetite and ilmenite) in the sandstones of the Westwater Canyon Member (Turner-Peterson, 1986). Iron leached from the detrital grains formed pyrite. More recent oxidation of pyrite (beginning in the Tertiary and continuing today) resulted in a yellowish-gray color in surface exposures of these sandstones. This first alteration event has been linked to the emplacement of primary uranium ore in the Westwater Canyon Member (Granger and Santos, 1986).

2. Further localized removal and/or reduction of iron from the sandstones in the Westwater Canyon Member sandstone was the result of the downward percolation of acidic, organic-rich fluids from carbonaceous shales of the Dakota Sandstone during the Late Cretaceous. This was only possible in the southwestern portions of the basin after the pre-Dakota erosion of the lacustrine Brushy Basin Member and deposition of carbonaceous black shales of the Dakota Sandstone directly on permeable sandstones of the Westwater Canyon Member (Turner-Peterson, 1986). The acidic nature of the organic-rich fluids derived from the Dakota resulted in leaching of feldspars (Turner-Peterson, 1986). Pronounced localized "bleaching" of the Westwater Canyon Member in the study area (e.g., White Rock Mesa) has been attributed by Turner-Peterson (1986) to this alteration event.

3. The red coloration of the sandstone is attributed by Granger and Santos (1986) to a subsequent oxidation event, which contributed to the formation of redistributed uranium ore within the member. This occurred because of an increase in hydrodynamic flow of oxidizing meteoric water from the uplifted southern edge of the San Juan Basin along the Zuni Uplift (Figs. 1a, b) during the Tertiary associated with the regional Laramide orogeny (Granger and Santos 1986). Sandstones that escaped earlier removal and/or reduction of iron in the previous reducing events were oxidized and now display a prominent red coloration. The intermediate buff-colored sandstones may have been partially leached of iron during the two earlier alteration events, so that these sandstones were not as readily reddened during the later Tertiary oxidation event (Turner-Peterson, 1986, pers. commun., 1990).

**Reassessment of Campbell's architectural model.** The ~5- to 10-m-thick sandstone sheets, irrespective of their color, are here recognized as the largest architectural component of the Westwater Canyon Member, whereas the thicker sandstones represent intervals of amalgamated sandstone sheets. It is apparent that the presence or absence of impermeable tabular overbank deposits exerted primary

control on the migration of pore fluids through the Westwater Canyon Member during its burial history, and hence the subsequent color variation of the member (Figs. 3, 6).

Campbell (1976) identified two scales of channel-filling deposits. The largest, which he termed "channel systems", are shown in his constructed profile of the Westwater Canyon Member (reproduced in Fig. 3 herein). He described the "channel systems" to be:

"...tabular in cross-section with abrupt edges only at the channel edges. Separate channel systems commonly are marked by contrasting overall colors on outcrops such as grayish-red versus salmon-pink versus buff" (Campbell, 1976, p. 1013).

According to Campbell's cross section, the abrupt "channel system" edges were mostly inferred and are shown as dashed lines (Campbell, 1976, his Fig. 2). The color differences in the sandstones were partly used in the definition of the "channel system" boundaries as defined by Campbell (1976). The White Cliffs section (Fig. 5), which coincides with Campbell's section 1, can be broadly divided into two units according to the sandstone color at any one vertical section. These color units can be clearly correlated to Campbell's section as representing "channel system" bodies (Figs. 3, 6). At the location of Campbell's measured section 3, the Westwater Canyon Member is divided into two "channel system" deposits, again corresponding to two distinct differences in sandstone color. It is evident that the uppermost "channel system", which is represented at Campbell's sections 2, 3 and 4, coincides with the white to buff sandstone color as documented in the upper profile of Figs. 6 (6 to 10.6 km along transect). There is a complex of channel deposits figured in Campbell's cross section between Kit Carson's Cave area and Midget Mesa (sections 4 to 8), where the "channel system" boundaries were apparently established using a combination of the sandstone color and the presence of overbank material between the sandstone sheets. At section 9 (Fig. 6, 21.2 km along transect), however, the boundary follows the above-mentioned color change criterion, and the "channel system" boundaries clearly coincide with the color change seen in the exposure.

Lateral color changes were not observed to coincide with sandstone-sheet edges and do not represent depositional features, but they do seem to coincide in places with the geometry of Campbell's (1976) "channel systems". It can be concluded, therefore, that Campbell (1976) was partly identifying post-depositional aquifer conduits or permeability-pathway compartments as primary depositional features. Furthermore, his cross section cannot be used as a map of post-depositional aquifers, since some of his channel boundaries are not defined solely by the sandstone color change, and many of the channel boundaries correspond to areas of no outcrop (Fig. 6). It is evident that the depositional "channel systems" of Campbell (1976), in the order of tens of meters thick, do not exist; instead, the ~5- to 10-m-thick sandstone sheets are here recognized as the principal architectural component of the Westwater Canyon Member.

#### PART II: INTERNAL ARCHITECTURE OF THE SANDSTONE SHEETS

The sandstone sheets, as described earlier, are internally composed of structures that were termed "smaller channels" by Campbell (1976). These structures, as well as large macroforms, are described and interpreted in this section.

#### Lateral Profiles of the Kit Carson's Cave Area

The Kit Carson's Cave area is located approximately 1 km southeast of White Rock Mesa, and 4 km north-northeast of Red Rock State Park (Figs 1b, 4). Three profiles, White Rock Mesa East, Kit Carson's Cave East and Kit Carson's Cave West, are stratigraphically located immediately above the Westwater and Raptus Member contact, and the Hill Top Road profile lies just below the Westwater Canyon Member-Dakota Sandstone contact (Fig. 1b). The strata are tilted approximately 4° to the north-northeast. However, since the tilt is not appreciable, and to avoid introducing error in the data processing, the individual azimuth data were not rotated to horizontally. The paleocurrent azimuth data illustrated on the detailed profiles are plotted with respect to the outcrop orientation (cf. Miall, 1988a), as indicated on the left side of each profile (Figs 7, 10, 13 and 16). Note also the scale differences between each profile.

**White Rock Mesa East (Fig. 7).** The west half of this profile was previously documented by Miall and Turner-Peterson (1989, Fig. 15). The profile shown in Figure 7 of this paper contains paleoflow data from parting lineations not documented previously by Miall and Turner-Peterson (1989). Although the profile appears somewhat complex in terms of the number of subhorizontal third- and fifth-order surfaces that occur here, it is relatively simple when reduced down to intervals of coherent paleocurrent orientation, as indicated by the black arrows of cross-strial dip directions (X) and parting lineation trends (P) (Fig. 7). Internally uniform paleocurrent intervals 1, 2 and 3, presented in Figure 8a and Table 2, correspond to sandstone units bounded by fifth-order bounding surfaces A-A', A'-A'', and A''-A''' respectively. The succeeding sandstone sheet is indicated by the fifth-order bounding surface B (surface not identified with primes represent laterally extensive fifth-order bounding surfaces, which are underlain by overbank fines, whereas surfaces with primes are laterally extensive fifth-order surfaces which are not underlain by overbank fines; third-order bounding surfaces comprise the remaining thick lines in the lateral profiles). The sandstone sheet represented by A to A''' most likely represents an amalgamated sandstone body, judging from the presence of locally preserved rafts of laumontite along bounding surface A', and the fact that the paleocurrent trend of sandstone unit 1 between surfaces A and A' is highly divergent from the overlying sandstone units 2 and 3 (Fig. 8a). The high paleoflow dispersion was interpreted by Miall and Turner-Peterson (1989) to be the product of localized low-stage concentration of flow around erosional bar remnants. This may be the case for the middle sandstone unit 2, where orientations of parting lineations and corresponding cross-strial dips differ (Fig. 8a), but the lower sandstone unit 1 can be interpreted as the result of channel flow at an angle to the rest of the fluvial system (at a much wider scale than the exposure). The top sandstone unit 3 is dominated by lithofacies S1 and S1, and displays highly random orientations of paleoflow structures from which the exact paleoflow direction cannot be determined (Fig. 8a, Table 2).

A striking aspect of this exposure is the presence of concave-up features which are bounded by discordant erosional basal third-order surfaces (BS3) (Fig. 9). There are several of these large structures in this profile, and they resemble "smaller channels" of Campbell (1976, his Fig. 5). These are commonly filled with lithofacies S1 and S1. The large concave-up "hollow" (see descriptive terminology of Friend 1983) marked "V" (in Fig. 7) is symmetrically and vertically filled from both sides (Fig. 9). The longitudinal axial orientation of this

particular structure trends 10°/250°. The lateral profile is, therefore, orientated oblique to the axial trend of this hollow. The significant axial dip of this structure indicates the non-horizontal and non-cylindrical nature of this hollow. Note that the axial dip azimuth of this hollow is obliquely upsteep with respect to the paleoslope indicated by the surrounding paleoflow orientations (Fig. 9a, Table 2). The axial dip of one other hollow in this area indicated downsteep dip with respect to the paleoslope, showing these hollows to be trough-like in three-dimensional geometry. However, plan exposures of these hollow structures are rare; thus, the three-dimensional aspect of this structure is poorly known. Unlike coasts of smaller trough cross-stratification, hollows commonly occur isolated from each other, but in some areas are grouped as described in the next section.

**Kit Carson's Cave East (Fig. 10).** This profile, located 0.5 km southeast of the east end of White Rock Mesa East profile, features horizons of overbank fines being truncated, and sandstone bodies becoming amalgamated to the south (i.e. to the right of profile). The lower horizon of overbank fines corresponds to the overbank fines located directly above sandstone unit 3 of White Rock Mesa East profile, and bounding surfaces A and B both correspond to bounding surfaces A and B of White Rock Mesa East profile (Fig. 7). The bounding surfaces marked with primes, however, are not likely the same surfaces as illustrated in the previous profile. The paleoflow is into the profile, enabling fairly good cross-sectional geometries to be determined from this exposure (Figs 8b, 10). Unfortunately most of the middle portion of this exposure is inaccessible, but it can be clearly seen from the profile that the dominant lithofacies is S1/S1 with some displaying parting lineations on their bedding surfaces. It can be appreciated from the profile that there is no meaningful cyclicity within the sandstone bodies in terms of their component lithofacies (Fig. 10).

As in the previous profile, the striking features are the large hollows, seen here in transverse view (Fig. 10). Detailed examination of the large-scale hollow on the central north end of the profile, labeled 'O', indicates lateral and oblique fill of the hollow with S1/S1 lithofacies exhibiting parting lineation on the bedding surfaces (Figs 11). The internal disposition of the stratified S1/S1 lithofacies can vary quite dramatically from one hollow to another; some being vertically filled (V), whereas others are laterally filled (L), or combinations of the above. In one case the lateral fill was composed of avalanche-face deposition, with angle-of-repose fine- to medium-grained sandstone (L1 Fig. 12). Hollows in the middle of the profile occur in a group, apparently along one horizon above a pebble clast-rich, laterally-continuous fifth-order bounding surface B', whereas other hollows are distinctly isolated. However, even when present in groups, the internal organization of the hollows and their scale is not uniform from one hollow to another (Fig. 10).

Shallow northerly dipping second- and third-order bounding surface traces can be identified between fifth-order bounding surfaces B and B', along the southern and central portion of the profile (L.A.). These dipping surfaces, which are bounded on the base by flat erosional surfaces, most likely represent sheet-like lateral-accretion elements, as described elsewhere from the Westwater Canyon Member by Miall and Turner-Peterson (1989). These features, however, contrast with the hollows, which are laterally restricted by concave-up third-order erosional bounding surfaces.

**Kit Carson's Cave West (Fig. 13).** The Kit Carson's Cave West profile is located 0.5 km southwest of Kit Carson's Cave East profile and their orientations are essentially the same (Fig. 4), but the Kit Carson's Cave West cliff exposure faces east. The paleoflow, therefore, is out of the profile, as indicated by the

Continued on page 86

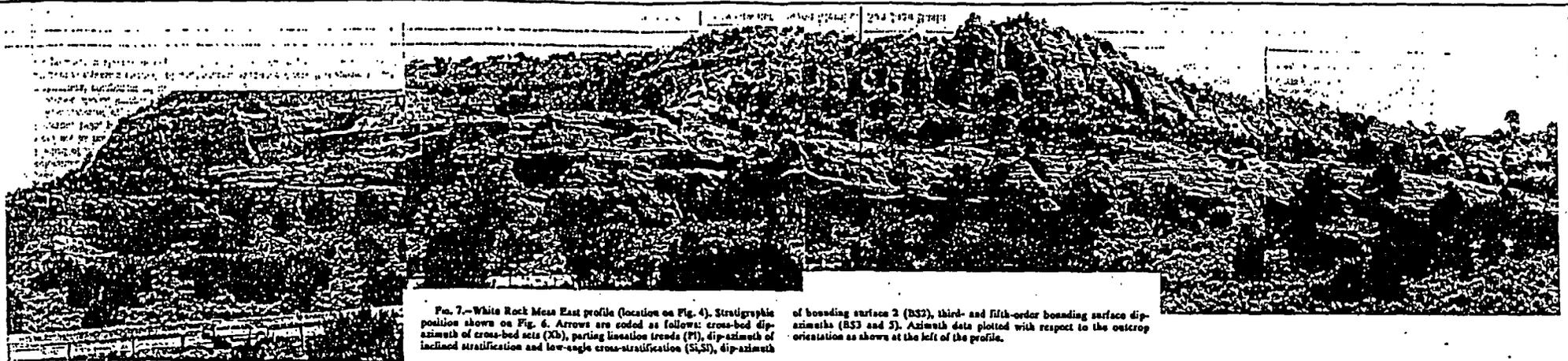
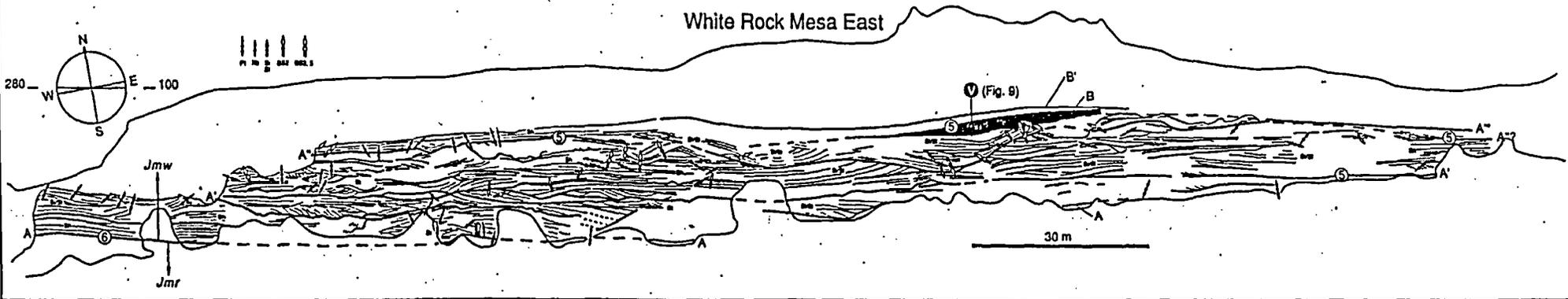


FIG. 7.—White Rock Mesa East profile (location on Fig. 4). Stratigraphic position shown on Fig. 6. Arrows are coded as follows: cross-bed dip-azimuth of cross-bed sets (Xb), parting lamination trends (Pl), dip-azimuth of inclined stratification and low-angle cross-stratification (Si, S1), dip-azimuth

of bounding surface 2 (BS2), third- and fifth-order bounding surface dip-azimuths (BS3 and 5). Azimuth data plotted with respect to the outcrop orientation as shown at the left of the profile.



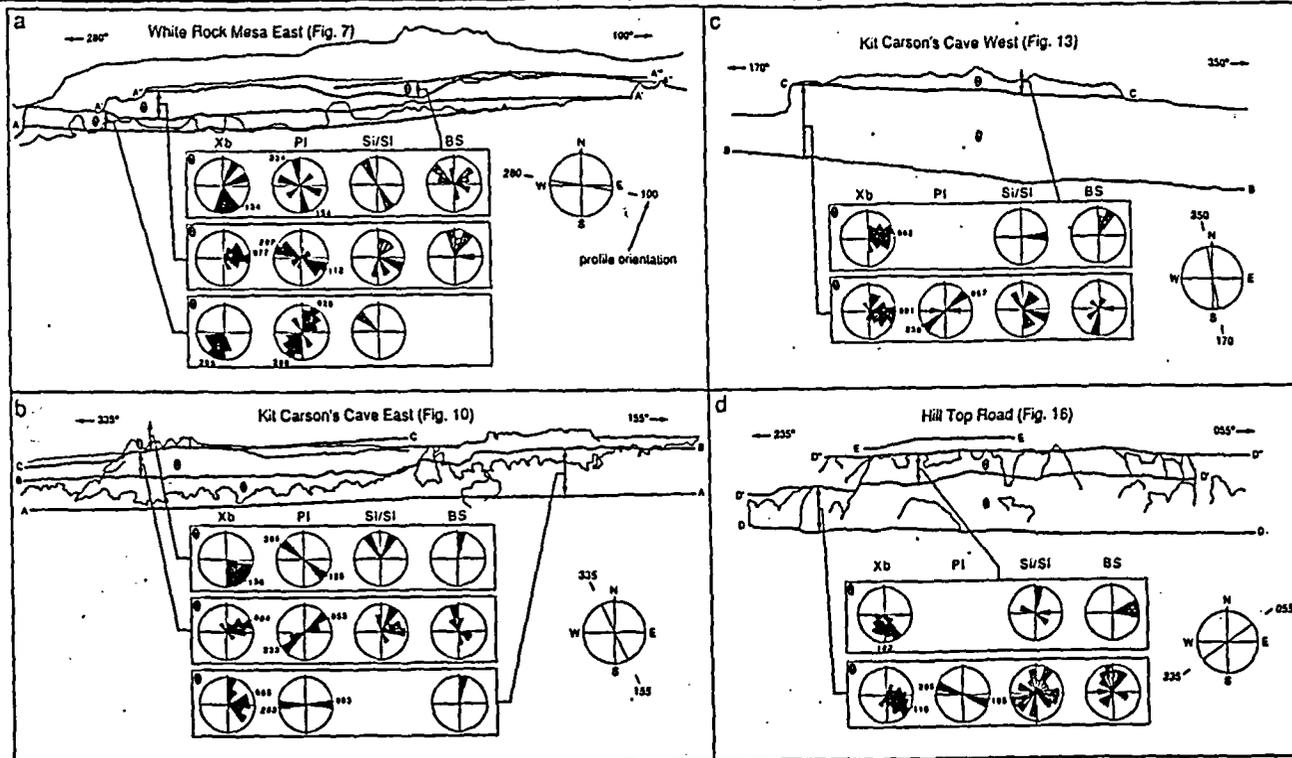


FIG. 8.—Paleocurrent, Si/Si, and bounding surface orientation summary diagram for a. White Rock Mesa East; b. Kit Carson's Cave East; c. Kit Carson's Cave West; and d. Hill Top Road. The orientation data are

subdivided into coherent intervals separated by fifth-order bounding surfaces. Paleocurrent statistics are summarized in Table 2.

TABLE 2.—The paleocurrent and vector dip-salmuth statistics of the Kit Carson's Cave area profiles, as presented in Fig. 8. WRM East = White Rock Mesa East Profile; KCC East = Kit Carson's Cave East Profile; KCC West = Kit Carson's Cave Profile; ITR = Hill Top Road Profile. n = number of observations; V.M. = vector mean azimuth;  $\sigma$  = circular standard deviation;  $\chi$  = Raleigh's  $\chi$  test of random distribution (at the 5% significance level) where R, U, and B indicate random, nonrandom unidirectional and nonrandom bipolar distributions respectively.  $\chi$  test not conducted for sample numbers less than five.

	Xb				PI				Si/Si				BS				
	n	v.m.	$\sigma$	$\chi$	n	v.m.	$\sigma$	$\chi$	n	v.m.	$\sigma$	$\chi$	n	v.m.	$\sigma$	$\chi$	
WRM East	1	7	205	27	U	9	208	25	B	2	316	2	-	15	077	29	U
	2	15	077	29	U	15	112	26	B	7	087	74	R	8	018	32	U
	3	5	124	71	R	6	154	44	R	2	247	155	-	10	004	89	R
KCC East	1	11	065	48	U	2	282	3	-	-	-	-	1	000	-	-	
	2	20	064	31	U	8	052	9	B	18	054	40	U	9	015	72	R
	3	4	136	28	-	1	125	-	-	2	002	29	-	1	010	-	-
KCC West	1	40	091	47	U	4	058	15	-	7	086	67	R	14	192	78	R
	2	16	242	26	U	-	-	-	-	1	095	-	-	3	025	8	-
	1	43	116	41	U	1	105	-	-	31	059	130	R	14	241	83	U
ITR	2	25	183	35	U	-	-	-	-	6	027	70	U	2	074	8	-

black arrows of cross-stratal dip directions (Xb) and paring lineation trends (PI) (Fig. 13). In places, the outcrop is characterized by laterally extensive fifth-order bounding surfaces (A, B, B', C), whereas elsewhere it is dominated by discontinuous third-order bounding surfaces with locally very steep angular contacts (up to 26°). The laterally continuous bounding surfaces, with the exception of A, could not be demonstrated to be the equivalent of the surfaces of the previous two profiles, nor could paleocurrent trends within packages be correlated, illustrating the difficulty of correlating depositional packages from one exposure to another in this erosionally dissected terrain.



Fig. 9.—Vertically filled hollow (with Si) at White Rock Mesa East profile (see Fig. 7 for location). The axis of the structure dips  $\sim 10^\circ$  toward the viewer, which is roughly up-paleocurrent. The staff is 1.5 m long. Direction of view  $070^\circ$ .

The large inclined structure in the center of the profile (O) is an oblique view of another hollow, which is laterally/obliquely filled with lithofacies Si/Si, with minor St and Sth lithofacies (Fig. 14). The paleoflow is obliquely out and to the left in the lower sandstone unit 1 (Fig. 8c), and consistent with the axial trend of the hollow being slightly oblique to the exposure. The hollow and its fill resemble a lateral-accretion structure from this view (element LA of Miall, 1983), and similar structures were interpreted as such by Miall and Turner-Peterson (1989). On the other hand, its concave-up basal surface indicates it is a negative (erosional) feature, as opposed to the positive (constructional) feature of element LA normally developed on a laterally extensive flat erosional surface. A steep concave-up basal erosion surface also bounds the southern margin of another hollow marked "V". The discordant basal bounding surface dip of the hollow "V" is  $26^\circ$  (Fig. 13), which is close to the maximum stable angle-of-repose for fine- to medium-grained sand.

In contrast to these laterally limited hollows, the structure labeled "LA" may represent a lateral-accretion element (LA of Miall, 1983, 1984a, c). Its basal erosion surface is laterally extensive, and clearly flat, suggesting a lateral-accretion macroform developed on a laterally extensive flat erosional surface.

**Hill Top Road (Fig. 16).** The Hill Top Road profile, located 0.4 km east-southeast of White Rock Mesa East profile (Fig. 4), is the most detailed profile constructed in this area, and stratigraphically the highest profile from the Kit Carson's Cave area. The uppermost sheet sandstone present in the Kit Carson's

Cave East profile (Fig. 10), bounded at the base by surface C, can be traced laterally to the base of Hill Top Road profile, where it is bounded on its top by surface D (Fig. 16). Most of the bounding surfaces, including first-order ones, can be seen in this profile, defining cross-stratified sets in the upper sandstone unit 2 (Figs 8d, 16). It can be seen that Si in some places is gradational to lithofacies Si/Si. The lower unit is characterized by abundant Si/Si lithofacies, some of which appear as broad concave-up stratification. Isolated trough-shaped Sth structures occur in the center and center left of the profile.

Upper sandstone unit 2, as represented by the unimodal orientation of sedimentary structures and uniform thickness, most likely represents a single channelbed sandstone sheet, as described in part I of this paper. Bounding surface D' is most likely the base of a channelbed sheet sandstone, judging from the abundance of interclasts along this horizon. However, lateral exposures of this bounding surface do not reveal any preserved overbank fine deposits, which may have been lost due to extensive downcutting. The differences in paleocurrent orientations between sandstone units 1 and 2 (Fig. 8d) also support this interpretation, as the paleoflow in the lower sandstone unit 1 is out of the profile, whereas paleoflow in the upper unit is obliquely out to the left (Figs. 8d, 16). The sandstone interval D to D' here, therefore, most likely represents an amalgamated composite-sheet sandstone.

An inclined feature (O) is noticeable in the central portion of the profile, but its

lateral extent to the right is not clear. Although its upper bounding surface appears locally convex-up, this is due to a perspective problem of an overhang. The structure seems to be localized and the concave-up nature of the lower third-order bounding surface can be better seen from the west, looking obliquely at the cliff face, suggesting an equivalence to the hollow structures seen elsewhere in the other profiles from this area. The structure is most likely skewed in orientation to the right (southeast) with respect to the underlying paleoflow indicators, and represents an oblique longitudinal section through a hollow. The other shallow structures, as expressed by the broad concave-up Si/Si laminations in the lower sandstone unit 1, are most likely shallow versions of the concave-up hollows.

The lithofacies contacts present between bounding surfaces D' and D'' are greatly inclined to the left and may represent shallow laterally accreted surfaces similar to the dipping surfaces present in Kit Carson's Cave East profile as described above.

#### Interpretation of the internal sandstone-sheet architecture

Paleocurrent variability, as determined from a. the axes of trough cross-stratification, and b. parting lineation within the individual sandstone sheets, is remarkably consistent at any one location in the Kit Carson's Cave area (Fig. 8). This may indicate that the sandstone sheets record a single depositional/aggradational event. In some areas (e.g., White Rock Mesa East and Hill Top Road), it is difficult to determine if the fifth-order bounding surfaces are the expression of individual sheet-channel fills within a larger sheet-channelbed sandstone body, or if they represent bases of amalgamated channelbed sandstone deposits. In the absence of overbank fine deposits between the sandstone sheets, it was difficult to determine with certainty which is the case.

The origin of hollows described above can be interpreted in several ways. They may represent: 1. large-scale dune structures with only their toe-sets preserved; 2. elongate channels ("smaller channels" as speculated by Campbell, 1976, his Fig. 3, 3); or 3. some other type of scour-fill structure formed within the fluvial channel belt. The hollows were previously interpreted by Miall and Turner-Peterson (1989) to be ancient analogues of large elongate flute-like scours formed at channel bases, as documented by Coleman (1969) from the Brahmaputra River. The physical processes involved in the formation of these flute-like scours are not yet known. Similar, but smaller scale structures, have been documented from an ephemeral stream deposit by Olaca (1989), and interpreted to have been formed from the erosional action of spiral vortices developed during a sheet flooding event.

The internal organization of the hollow fills are somewhat variable from one hollow to another, and they can occur as isolated sets (Figs. 7, 10, 13, 16). These features do not resemble the regularity of large cross-bed sets reported from other fluvial sandstones such as the Hawkesbury Sandstone (cf. Coscaugh and Jones, 1975), suggesting an origin other than that of dune preservation. Channels downcutting into sand banks, if formed, are not likely to be preserved with steep banks (in the order of  $15^\circ$  to  $30^\circ$ , as seen in the hollows of White Rock Mesa East and Kit Carson's Cave West profiles) due to the absence of fines sand, therefore, lack of bank cohesion. Furthermore, the fact that the hollows are most likely trough-shaped in three dimensions suggests an origin other than elongated channelization.

A process for forming deep scours, of up to six times the mean channel depth, by channel convergence, has been documented both from rivers and from laboratory flumes (Mowley, 1974; Mowley and Schumm, 1974; Best and Brayshaw, 1983; Best, 1987, 1988; Best and others, 1989). These studies suggest that a mechanism of deep scouring may be a significant process at channel junctions, and this is particularly

the case for the steady braided-stream environment, where stream junctions abound (cf. Best, 1987, p. 34; Best and others, 1989). Best (1987) for example has shown that avalanche faces can develop on the upstream end of these scours. This will allow the scours potentially to be filled laterally, obliquely or vertically by the avalanche deposit in a short period of time during channel switching or a flood event within a braided-fluvial setting. The scours are, therefore, envisaged to form as clusters or isolated features, depending on the density and spacing of the channels within a braided channelbelt.

Another mechanism of deep scouring in a braided fluvial environment was documented by Cant (1976) in the South Saskatchewan River. Cant (1976, p. 125) interpreted deep scours, reaching nearly three times the mean braided-channel depth, to have formed upstream of a large emergent bar. This process is analogous to scouring on the upstream margin of an obstacle clast in a flow (cf. Best and Brayshaw, 1983), with the emergent bar acting as an obstacle within the channel. This scour-and-fill process may also be a significant process governing the final depositional state of multichannel braided fluvial systems, in addition to the above mentioned scour process, which occurs at channel confluences. The laterally restricted hollows erode underlying material, which in some places appears to be composed of inclined lateral-accretion macroforms (Kit Carson's Cave East profile, Fig. 10). The hollows may represent initial stages in the development of laterally extensive macroforms, since their internal-stratification geometries appear similar.

#### DISCUSSION

##### Typical fluvial-sandstone body dimensions

Friend (1983) classified channels into three types: fixed, meandering, and braided, which result in two different types of sandstone-body morphology. Channels that are stable between avulsive events commonly create ribbon bodies, whereas channels that steadily migrate laterally within a channelbelt will create sheet-like sandstones, whether they are meandering or braided (Friend 1983).

The sheet sandstones, which represent channelbelt deposits that have aggraded between avulsive events, can form thicker amalgamated sandstone bodies if the subsidence between avulsive events is not fast enough to allow preservation of intervening overbank fines. The field distinction between individual sheet sandstone bodies (cf. Friend, 1983, p. 150) can only be made from interpretation of large, laterally continuous exposures orientated transverse to the paleoflow direction. At present there are a few documented examples indicating what range of thicknesses and widths individual sheet bodies can attain. Commonly, when figures are given, the authors do not specify which of the following four possible cases these dimensions represent: 1. dimensions of the channel-fill sandstones and fines within a larger channelbelt deposit; 2. dimensions of the channelbed deposit; 3. dimensions of an amalgamated channelbed deposit (i.e. composite sandstone bodies); or 4. some combination of the above cases. However, following the suggestions of Collinson (1978) and Friend and others (1979), reports of the cross-sectional dimensions of fluvial sandstone body dimensions have increased in the last decade, allowing a review of the expected ranges of channelbed sandstone body dimensions resulting from fluvial deposition. Published ranges of widths and thicknesses of sandstone bodies and their interpreted fluvial styles are summarized in Figure 17.

The data presented in Figure 17 can broadly be divided into three classes: sandbody dimensions that are divided into 1. ribbons and 2. sheets following the suggestion of Friend and others (1979) and shown as circles and squares, respectively, in Fig. 17, and 3. some thicker sandstone-sheet deposits that are

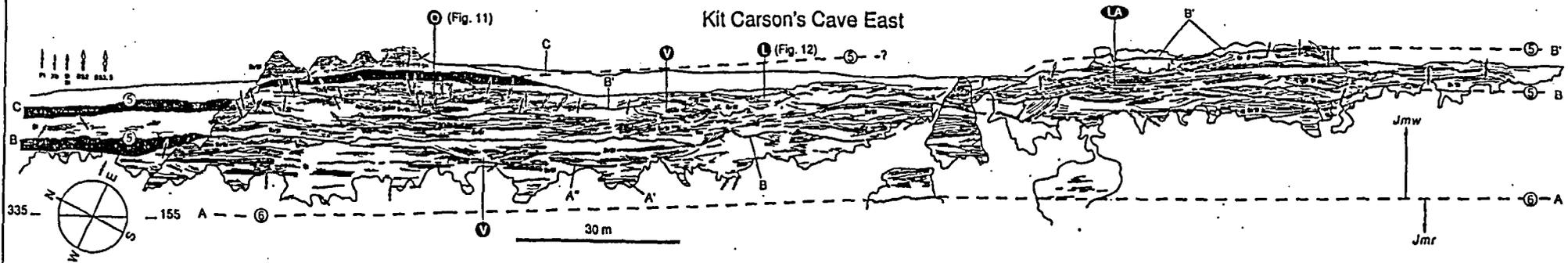


FIG. 10.—Kit Carson's Cave East profile (location on Fig. 4). Stratigraphic position shows on Fig. 6. Azimuth data same scheme as Fig. 7.



FIG. 11.—Southern erosional margin and fill of the hollow labeled "O" in Kit Carson's Cave East profile (see Fig. 10). The azimuth data (as indicated) show that the internal fill of lithofacies S1 is filled obliquely with respect to the strike of the hollow base. Direction of view 350°.



FIG. 12.—Direction of view 083° along strike of the south end of a hollow labeled "L" at Kit Carson's Cave East profile (see Fig. 10). The hollow is laterally filled by two cross-stratified sets. The 1.5 m scale on top is parallel to the plan trace of the cross-strata.

composite in nature (amalgamated sheets), as far as can be gathered from the documentation. This third class plots in the upper right of the diagram (shown as diamonds in Fig. 17). The single-sheet bodies, interpreted to be of channel/channel-belt origin, display wide ranges of sandstone widths, but they consistently show thicknesses less than 12 m. In general, the inferred braided deposits have a wider range of thicknesses than meandering deposits, but the reported sandstone-body dimensions cluster between 1 and 12 m in thickness. These figures, which are independent of fluvial style or tectonic setting, suggest that regardless of the original channel depth, erosion or some other processes result in the preservation of fairly consistent thicknesses of 1-12 m. It is worth noting that although thickness of sandstone sheets can easily be deciphered in the field, less confidence can be placed on actual widths of sandstone sheets, even in areas of wide exposure such as the Westwater Canyon Member, due to their very high width:thickness ratios. The range of channelbelt sandstone widths as plotted on Figure 17, therefore, most likely includes laterally amalgamated widths.

Exceptions to the channelbelt thicknesses of 1-12 m are those of non-channelbelt sheet-flood deposits (Olson, 1969; Tunbridge, 1981), which display very low thickness values of less than 1 m (18 and 31 in Fig. 17). One very thick point-bar channelbelt deposit (Mossop and Flach, 1983), and various fixed channels (Hopkins,

1985), both from the Alberta Fortland Basin, record preservation of very deep channel deposits in tidal to deltaic distributary settings, respectively 30 and 37 m (Fig. 17). Hopkins (1985, p. 49) suggested that deep channel incision is independent of base level changes in deltaic settings, pointing out that channelization of up to 60 m below sea level is reported from a modern delta distributary (Meckel, 1972). Further studies of fluvial sandbody geometries may reveal other deep-river channelbelt bodies and shed light on the controls of deep river deposition and preservation.

#### Dimensions of the Westwater Canyon Member sandstone bodies

The ~5-10-m-thick sheet-sandstone bodies of the Westwater Canyon Member represent channelbelt deposits that aggraded between avulsive events (Fig. 18). The consistent paleocurrent trends within a sheet sandstone deposit suggest that a single depositional event created each sheet-sandstone body. The estimated sandstone-body thicknesses of the Westwater Canyon Member are well within the range of the clustered values (shown as "w" in Fig. 17). In contrast, the sandstone thicknesses as reported by Campbell (1976) are within the range of amalgamated or composite sandstone bodies (shown as "w" in Fig. 17). The wide range of "channel-system"

dimensions as documented by Campbell (1976) is expected if amalgamation of more regular channelbelt deposits occurs at random (cf. Bridge and Leeder, 1979, see their Figs. 2c and 4c).

Cliff exposures of the Westwater Canyon Member serve as an excellent example for illustrating the control of overbank facies as effective barriers to pore-fluid flow. It is apparent that on the member scale, the preservation of overbank-fine deposits between sheet-like sandstone bodies has controlled the pore-fluid flow, notwithstanding the lateral complexity of the sheet-sandstone architecture as revealed by the detailed lateral profiles. The sheet sandstones, with very little internal grain-size variation, acted as fluid conduits, and the thicknesses of conduits or compartments were solely dependent upon the preservation of overbank facies between the interpreted channelbelt sandstone bodies. The review of published examples of fluvial-body dimensions indicates a consistency of sandbody thicknesses, namely in the 1- to 12-m range, and the thicknesses of the Westwater sheets fit in this range (Fig. 17). The pore-fluid flow, therefore, will be largely confined within this thickness for sandy fluvial systems. Increases in this thickness range will be the result of amalgamation of the unit sandstone sheets by erosion of capping overbank facies, whereas a decrease is likely to be associated with increasing heterogeneity of grain size within the sandstone channelbelt bodies (as in deposits resulting from mixed-load fluvial systems).

#### Implications of hollow preservation

Fluvial sedimentologists have concentrated on the sedimentary features formed from the migration of positive barforms, and used these structures to decipher styles of fluvial sedimentation (Allen, 1983b; Hazzekine, 1983; Miall, 1984a). Little attention has been directed to processes in the deepest portions of fluvial channels until only recently (e.g., Best and others, 1987). Theoretically, it is not considered possible to preserve the entire thickness of the channelbelt deposit, and entire macroforms, unless avulsion of the channel belt takes place (cf. Bridge and Leeder, 1979). However, scow-fill processes, as documented by workers such as Best (1987) and Cain (1976), are comparatively more ephemeral. In a multichannel fluvial system, thus life of constructional macroforms; it is likely that these structures with high preservation potential deposited in the deepest parts of the channel belts may dominate the geological record. The abundant hollows as seen in the Westwater Canyon Member may represent such scours from the deepest portions of the channel belt.

#### CONCLUSIONS

Several significant conclusions can be drawn from this study of the large-scale features of the Westwater Canyon Member.

1. The "channel systems" described by Campbell (1976, Fig. 3 herein) are not channelbelt deposits but records of post-depositional pore-water conduits composed of amalgamated, ~5-10-m-thick sheet sandstone bodies.
2. The individual sheet-sandstone-body thicknesses of the Westwater Canyon Member falls within the thickness ranges of sandstone bodies that are of possible channelbelt origin. Sandstone body thicknesses in excess of 12 m appear to result from channelbelt amalgamation.
3. Diagenetic pore-fluid flow was primarily controlled by the presence of thick overbank deposits which escaped erosion during amalgamation of channelbelt sandstone bodies. Published data on fluvial deposits indicate that large-scale pore-fluid conduits composed of homogeneous channelbelt sandbodies fall within the 1-

12 m thickness range. Departures from this range are expected to be due either to channelbelt amalgamation or higher heterogeneity within the sandstone sheet.

4. Internally, sheets display trough-like features 30 x 3 m in cross-section dimensions, commonly isolated, with varying orientations of internal fill. The interpretation of these large-scale hollow features is most consistent with a scour produced within the deepest portions of a shallow, braided-fluvial environment, possibly due to channel-confluence scouring. The variable inclination of the fills, with parting location on their bedding surfaces, are most consistent with a rapidly filled scour and are less consistent with forms produced from trains of large dunes or small channels, as previously interpreted.

5. The member contains low-amplitude, laterally extensive macroforms bounded by flat erosional surfaces, consistent with the interpretation that the style of the fluvial environment was a braided multichannel system. Hollows, on the other hand, are bounded by concave-up erosional surfaces and are interpreted to have been produced in the deepest portions of the fluvial channel belt, and hence have greater preservation potential than constructional macroforms.

#### ACKNOWLEDGMENTS

This work was completed while the author was the recipient of a Canadian Commonwealth Scholarship. Acknowledgment is made to the donors of the American Chemical Society Petroleum Research Fund, AAPG Grants in Aid, and to NSERC for support of this project through research grants to my supervisor A.D. Miall. I thank the Navajo Nation (Window Rock, AZ) for allowing field work to be conducted on the Navajo Indian Reservation. I am indebted both to Andrew Miall who initially suggested reexamining the large-scale architecture of the Westwater Canyon Member, and to Christine E. Turner-Peterson whose guidance in and out of the field was most appreciated. Andrew D. Miall, Greg C. Nadon, Alan C. Kendall, Nick Eyles and Paul D. Godin (who also assisted in the field) are thanked for stimulating discussion and comments on the manuscript during various stages of the study. Constructive criticism by reviewers C. E. Turner-Peterson and A. Ramos served to greatly improve the manuscript. The oblique aerial photographs used to construct Figures 5 and 6 were photographed by A.D. Miall and reproduced by Brian O'Donovan.

#### REFERENCES

- ALEXANDER, J., and LESPEL, M. R., 1987, Active, tectonic control on alluvial architecture, in Elshridge, F. G., Flores, R. M., and Harvey, M. D., eds, Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 243-252.
- ALLEN, J. R. L., 1978, Studies in fluvial sedimentation: An exploratory quantitative model for the architecture of avulsion-controlled alluvial suites: *Sedimentary Geology*, v. 21, p. 129-147.
- \_\_\_\_\_, 1983a, Gravel overpassing on bumpback bars with mixed sediment: examples from the Lower Old Red Sandstone, southern Britain: *Sedimentology*, v. 30, p. 285-294.
- \_\_\_\_\_, 1983b, Studies in fluvial sedimentation: bars, bar-complexes and sandstone sheets (low-sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders: *Sedimentary Geology*, v. 33, p. 237-293.



Kit Carson's Cave West

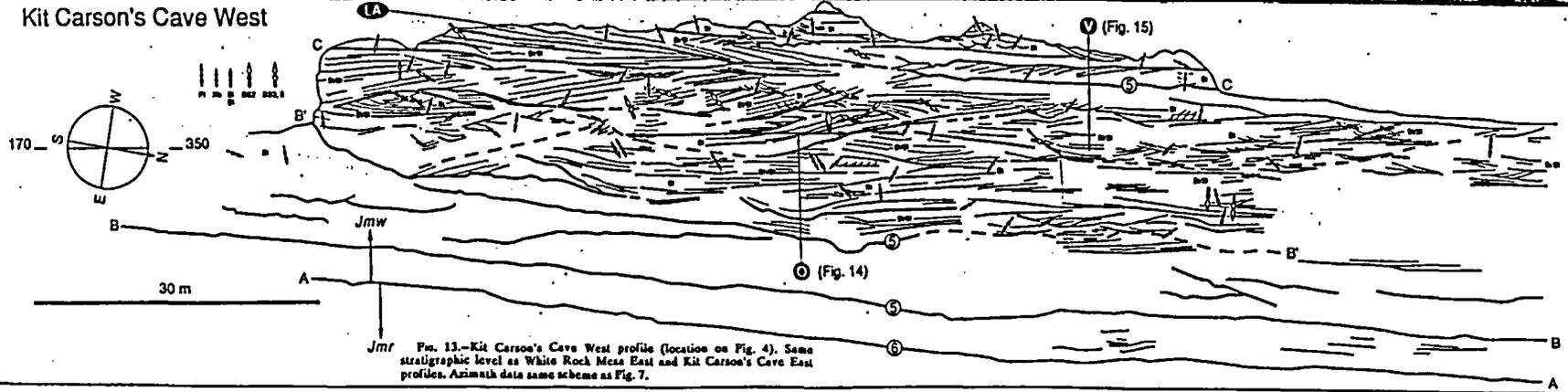


Fig. 13.—Kit Carson's Cave West profile (location on Fig. 4). Same stratigraphic level as White Rock Mesa East and Kit Carson's Cave East profiles. Azimuth data same scheme as Fig. 7.



FIG. 14.—A close-up view of the northern end of the large hollow labeled "O" at Kit Carson's Cave West profile (see Fig. 13). The discordant third-order bounding surface is marked by arrows. The fill is mainly lithofacies S1 and S2. Direction of view 260°.

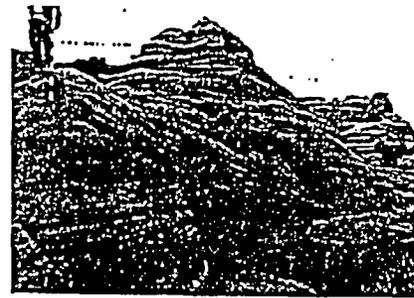


FIG. 15.—The southern erosional margin of the hollow labeled "V" at Kit Carson's Cave West profile (see Fig. 13). The dip of the basal margin and overlying attitude of lithofacies S1 is 26°. The staff with 10 cm markings rest on the basal surface trace. Direction of view 260°.

BEA, J. A., and JORDAN, T. E., 1989, The effects of Neogene thrusting on deposition in the Bermejo Basin, Argentina: *Journal of Sedimentary Petrology*, v. 59, p. 330-345.

ВЕРИЩЕВИЧ, А. К., and ТУРИН, Л., 1982, Isochronous fluvial systems in Miocene deposits of Northern Pakistan: *Sedimentology*, v. 29, p. 331-352.

BEY, J. L., 1987, Flow dynamics at river channel confluences: implications for sediment transport and bed morphology, in Eldridge, F. G., and Flores, R. M., eds, Recent and ancient nonmarine depositional environments, Society of Economic Paleontologists and Mineralogists Special Publication 31, p. 27-35.

\_\_\_\_\_, 1988, Sediment transport and bed morphology at river channel confluences: *Sedimentology*, v. 35, p. 481-498.

\_\_\_\_\_, and ВЛАДИМ, А. С., 1985, Flow separation - a physical process for the concentration of heavy minerals within alluvial channels: *Journal of the Geological Society, London*, v. 142, p. 747-753.

\_\_\_\_\_, ВАРНО, С. S., and РОУ, А. G., 1989, The morphology of river channel confluences: scales and dynamics, Program and Abstracts of the 4th International Conference on Fluvial Sedimentology, Barcelona, Spain, p. 75.

BLAKEY, R. C., and GURTON, R., 1984, Controls of sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: *Sedimentary Geology*, v. 34, p. 51-66.

BEAUS, J. S., and LEZAN, M. R., 1979, A simulation model of alluvial stratigraphy: *Sedimentology*, v. 26, p. 617-644.

САНЧЕЛ, С. V., 1976, Reservoir geometry of a fluvial sheet sandstone: *American Association of Petroleum Geologists Bulletin*, v. 60, p. 1009-1020.

CANT, D. J., 1976, Braided stream sedimentation in the South Saskatchewan River: unpublished Ph.D. thesis, McMaster University, Hamilton.

\_\_\_\_\_, 1978, Fluvial facies models and their application, in Scholte, P. A., and Spearing, D., eds, Sandstone depositional environments, American Association of Petroleum Geologists Memoir 31, p. 115-137.

COLEMAN, J. M., 1969, Brahmaputra River: channel processes and sedimentation: *Sedimentary Geology*, v. 3, p. 129-239.

COLLISON, J. D., 1978, Vertical sequence and sand body shape in alluvial sequences, in Miall, A. D., ed., Fluvial sedimentology, Canadian Society of Petroleum Geologists Memoir 5, p. 577-586.

\_\_\_\_\_, 1986, Alluvial Sediments, in Reading, H. G., *Sedimentary environments and facies*: Blackwell Scientific Publications, p. 20-62.

COMMONER, P. J., and JONES, J. G., 1975, The Hawkesbury Sandstone and the Brahmaputra: a depositional model for continental sheet sandstones: *Journal of the Geological Society of Australia*, v. 22, p. 275-283.

COWAN, E. J., 1990, The fluvial sedimentology of the Westwater Canyon Member, Morrison Formation (Jurassic), San Juan Basin, New Mexico, USA: unpublished M.Sc. thesis, University of Toronto, 162 p.

FRENCH, P. F., 1983, Towards the field classification of alluvial architecture or sequence, in Collinson, J. D., and Lewis, J., eds, Modern and ancient fluvial systems: International Association of Sedimentologists Special Publication 6, p. 345-354.

\_\_\_\_\_, SLATER, M. J., and WILLIAMS, R. C., 1979, Vertical and lateral building of river sandstone bodies, Ebro Basin, Spain: *Journal of the Geological Society, London*, v. 136, p. 39-46.

GALLOWAY, W. E., 1981, Depositional architecture of Cenozoic gulf coastal plain fluvial systems, in Eldridge, F. G., and Flores, R. M., eds, Recent and ancient nonmarine depositional environments: models for exploration: Society of

Economic Paleontologists and Mineralogists Special Publication 31, p. 127-155.

GERARD, M. R., and RYAN, B. R., 1990, Ribbon sandstones in the Pennsylvania Wadswade Cove Formation, Sydney Basin, Atlantic Canada: the influence of siliceous duricrusts on channel-body geometry: *Sedimentology*, v. 37, p. 45-65.

GOON, P. D., 1991, Fining-upward cycles in the sandy braided-river deposits of the Westwater Canyon Member (Upper Jurassic), Morrison Formation, New Mexico: *Sedimentary Geology*, v. 70, p. 61-82.

GRANOW, H. C., and SWARTZ, E. S., 1986, Geology and ore deposits of the Section 23 mine, Ambrosia Lake District, New Mexico, in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds, A basin analysis case study: Morrison Formation Grants Uranium Region New Mexico, American Association of Petroleum Geologists Studies in Geology 22, p. 185-210.

HACKMAN, R. J., and OLSON, A. B., 1977, Geology, structure and uranium deposits of the 12' quadrangle, New Mexico and Arizona, U.S. Geological Survey Miscellaneous Investigations Series I-981, scale 1:250,000.

HAMPTON, P. L., 1986, Regional diagenetic trends and uranium mineralization in the Morrison Formation across the Grants Uranium Region, in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds, A basin analysis case study: The Morrison Formation Grants Uranium Region New Mexico, American Association of Petroleum Geologists Studies in Geology 22, p. 277-301.

HARRISON, R. S., 1983, Fluvial bars reconstructed from a deep, straight channel, Upper Carboniferous coalfield of northeast England: *Journal of Sedimentary Petrology*, v. 53, p. 1233-1247.

HORVAT, J. C., 1985, Channel-fill deposits formed by aggradation in deeply scoured, superimposed distributaries of the Lower Kootenai Formation (Cretaceous): *Journal of Sedimentary Petrology*, v. 55, p. 42-52.

KRAM, M. J., and MACKENZIE, L. T., 1987, Contrasting architecture of two alluvial suites in different structural settings, in Eldridge, F. G., Flores, R. M., and Harvey, M. D., eds, Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 253-262.

LEVINE, D. A., and WASSON, B. P. J., 1987, Evolution of drainage systems in response to Acadian deformation: The Devonian Battery Point Formation, eastern Canada, in Eldridge, F. G., Flores, R. M., and Harvey, M. D., eds, Recent developments in fluvial sedimentology: Society of Economic Paleontologists and Mineralogists Special Publication 39, p. 263-300.

LEZAN, M. R., 1978, A quantitative stratigraphic model of alluvium with special reference to channel deposit density and interconnectivity, in Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 587-596.

\_\_\_\_\_, 1982, Sedimentology: London, George Allen and Unwin, 343 p.

MARZO, M., NUNAN, W., and PUNOYANANDAN, C., 1988, Architecture of the Castejón fluvial sheet sandstones, Eocene, South Pyrenees, Spain: *Sedimentology*, v. 35, p. 719-738.

MACIEN, I. D., 1972, Anatomy of distributary channel-fill deposits in Recent mud deltas (Abstract): American Association of Petroleum Geologists Bulletin, v. 56, p. 639.

MIALL, A. D., 1978, Lithofacies and vertical profile models in braided river deposits: a summary, in Miall, A. D., ed., Fluvial sedimentology, Canadian Society of Petroleum Geologists Memoir 5, p. 597-604.

\_\_\_\_\_, 1985, Architectural-Element Analysis: a new method of facies analysis applied to fluvial deposits: *Earth Science Reviews*, v. 22, p. 261-308.

\_\_\_\_\_, 1988a, Architectural elements and bounding surfaces in fluvial deposits: Anatomy of the Kayenta Formation (Lower Jurassic), southwest Colorado: *Sedimentary Geology*, v. 55, p. 233-262.

\_\_\_\_\_, 1988b, Reservoir heterogeneities in fluvial sandstones: lessons from outcrop studies: American Association of Petroleum Geologists Bulletin, v. 72, p. 682-697.

\_\_\_\_\_, 1988c, Facies architecture in classic sedimentary basins, in Kleinspehn, K. L., and Paola, C., eds, New Perspectives in basin analysis: New York, Springer-Verlag, p. 67-81.

\_\_\_\_\_, and TURNER-PETERSON, C. E., 1989, Variations in fluvial style in the Westwater Canyon Member, Morrison Formation (Jurassic), San Juan Basin, Colorado Plateau: *Sedimentary Geology*, v. 63, p. 21-60.

MONTE, M. P., 1976, An experimental study of channel confluences: *Journal of Geology*, v. 84, p. 535-562.

\_\_\_\_\_, and SCHMIDT, S. A., 1976, Stream junctions - a probable locations for bedrock placers: *Economic Geology*, v. 72, p. 691-697.

MONROE, G. D., and FLUCH, P. D., 1983, Deep channel sedimentation in the Lower Cretaceous McMurray Formation, Athabasca Oil Sands, Alberta: *Sedimentology*, v. 30, p. 493-509.

NASH, M., and LEZAN, M. R., 1978, Changing channel morphology and magnitude in the Scabby Formation (M. Jurassic) of Yorkshire, England, in Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 431-440.

OLSON, H., 1989, Sandstone-body structures and ephemeral stream processes in the Dinorath Canyon Member, Moenave Formation (Lower Jurassic), Utah, U.S.A.: *Sedimentary Geology*, v. 61, p. 207-221.



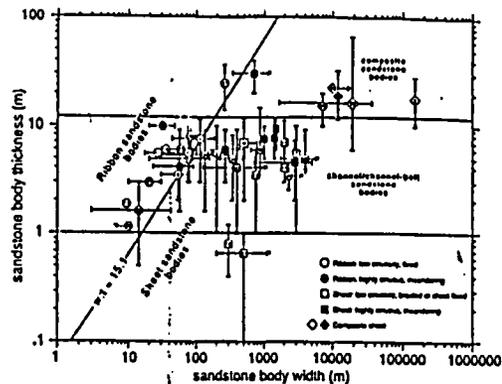


FIG. 17.—Log/log plot of published width:thickness dimensions of sandstone bodies, with ranges indicated by the bars. Published data which did not indicate ranges are not plotted with bars. Sources as follows: 1 and 2, Abrahamkraal Fm., Stear (1960); 3-6, Chiale Fm., Blakey and Gubitosa (1964), width ranges of 4 and 6 estimated assuming width:thickness ratio of 15:1; 7 and 8, Cadizian Fm., Morin and others (1968); 9, Middle Siwalik, Behrensmeyer and Texe (1967); 10 and 11, Scalby Fm., Nami and Leeder (1978); 12, Pi Prevel Fm., Levrone and Williams (1987); 13-16, Oligocene and Miocene of Ebro Basin, Fried and others (1979); 17-19, Brownstones, Trunbrigg (1981); 20 and 21, Salt Wash Member, Morrison Fm., Peterson (1964), width ranges of 22 estimated assuming width:thickness ratio of 15:1; 22-24, Willwood Fm., Kraus and Middleton (1987); 25, George West Asia, Oakville Fm., Galloway (1981); 26 and 28, Archer City and Neocom Fms., Sander (1989); 29, Beaufort Fm., Turner and Whately (1983); 30, McMurray Fm., Messop and Flock (1983); 31, 32 and 33, sheet, simple and multistoried sandbodies respectively, Dinosaur Canyon Mbr., Moccasin Fm., Oleca (1989); 34, 35 and 36, Jarillal, Huachipampa and Quebrada del Cura Fms., Boer and Jordan (1989); 37, Lower Kootzai Fm., Hopkins (1983); 38, Waddens Cove Fm., Gibling and Rust (1990); W, 'channel system' dimensions of the Westwater Canyon Member as given by Campbell (1976); w, estimated sheet sandstone body dimensions of the Westwater Canyon Member as presented herein, minimum width only, maximum not known.

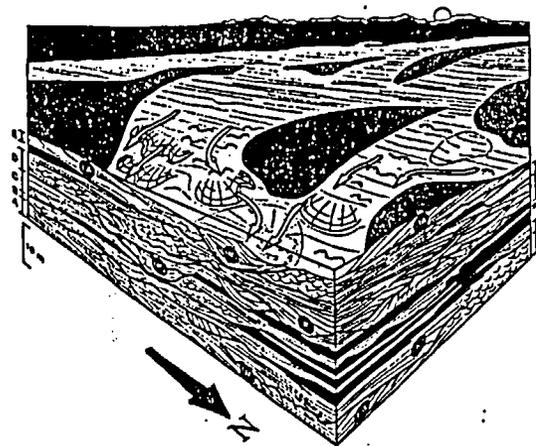


FIG. 18.—The large-scale architectural model of the Westwater Canyon Member fluvial system. The block diagram illustrates waning-stage flow, seen looking toward the southwest and the Late Jurassic magmatic arc. The sandstone units produced between each avulsive event of the channel belt are approximately 5 m thick, and are bounded by laterally-extensive fifth-order bounding surfaces. The width of the sandstone sheets is most likely > 1 km. The sandstone bodies can be either single or composite channel-belt sandstones, depending on their vertical stacking, as shown by the examples of sandstone sheets A to E. The large boulders (labelled HO) within the sandstone sheets are interpreted as channel-confluences occur produced downstream of emergent channel sand bars, which in turn produce low-amplitude lateral accretion (LA) and downstream accretion (DA) deposits.

- PAOLA, C., WILK, S. W., and REINHART, M. A., 1989, Upper-regime parallel lamination as the result of turbulent transport and low-amplitude bedforms: *Sedimentology*, v. 36, p. 47-59.
- PETerson, P., 1984, Fluvial sedimentation on a quivering craton: Influence of slight crustal movements on fluvial processes, Upper Jurassic Morrison Formation, western Colorado Plateau: *Sedimentary Geology*, v. 38, p. 21-30.
- SANDER, P. M., 1989, Early Permian depositional environments and pond basins in central Archer County, Texas: *Paleogeography, Paleoclimatology, Paleontology*, v. 69, p. 1-21.
- SANTOS, E. S., and TURNER-PETERSON, C. E., 1986, Tectonic setting of the San Juan Basin in the Jurassic, in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds, A basin analysis case study: Morrison Formation Grants Uranium Region New Mexico, American Association of Petroleum Geologists Studies in Geology 22, p. 27-33.
- SANDERSON, H. C., and LOCKETT, P. P. J., 1983, Flume experiments on bedforms and structures at the dune-plane bed transition, in Collinson, J. D., and Lewin, J., eds, Modern and ancient fluvial systems: International Association of Sedimentologists Special Publication 6, p. 49-58.
- STEAR, W. M., 1980, Channel sandstone and bar morphology of the Beaufort Group uranium district near Beaufort West: *Transactions of the Geological Society of South Africa*, v. 83, p. 391-398.
- TRUNBRIGG, I. P., 1981, Old Red Sandstone Sedimentation - An example from the Brownstones (highest Lower Old Red Sandstones) of South Central Wales: *Geological Journal*, v. 16, p. 111-124.
- TURNER, B. R., and WHATELY, M. K. G., 1983, Structural and sedimentation controls of coal deposition in the Nongoma graben, northern Zululand, South Africa, in Collinson, J. D., and Lewin, J., eds, Modern and ancient fluvial systems, International Association of Sedimentologists Special Publication 6, p. 457-471.
- TURNER-PETERSON, C. E., 1983, Lacustrine-humate model for primary uranium ore deposits, Grants uranium region, New Mexico: *American Association of Petroleum Geologists Bulletin*, v. 69, p. 1999-2020.
- \_\_\_\_\_, 1986, Fluvial sedimentology of a major uranium-bearing sandstone - a study of the Westwater Canyon Member of the Morrison Formation, San Juan Basin, New Mexico, in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds, A basin analysis case study: Morrison Formation Grants Uranium Region New Mexico: American Association of Petroleum Geologists Studies in Geology 22, p. 47-75.
- \_\_\_\_\_, and FISHMAN, N. S., 1986, Geologic synthesis and genetic models for uranium mineralization in the Morrison Formation, Grants uranium region, New Mexico, in Turner-Peterson, C. E., Santos, E. S., and Fishman, N. S., eds, A Basin Analysis Case Study: Morrison Formation Grants Uranium Region New Mexico: American Association of Petroleum Geologists Studies in Geology 22, p. 337-388.
- \_\_\_\_\_, 1988, Origin and distribution of albite, ilite/smectite, and chlorite in Jurassic Lake To'o'dichi: consequence of early diagenesis in saline, alkaline lake: *Geological Society of America Abstracts with Program*, v. 20, p. A51-52.

## MINING FLUID CONTAINMENT

### Vertical Containment

A pumping test was conducted on the Westwater Canyon Member of the Morrison Formation. Observation wells completed in the overlying Brushy Basin Member and Dakota Sandstone and an observation well completed in the lowermost sand of the Westwater Canyon Member were monitored throughout this test. The data from this pumping test was included in the Environmental Assessment Report as part of the application for a discharge permit. During the pumping test, water levels in the pumping well were lowered approximately 125 feet. A nearby Westwater Canyon well, 400 feet from the pumped well, had a water level decline during the test of about 16 feet. However, the water levels in the Brushy Basin well, located less than 100 feet from the pumped well, rose throughout the pumping portion of the test, thus confirming that the shales in the base of the Brushy Basin Member will prohibit upward migration of mining fluids from the mine zone. Water levels in the Dakota Sandstone monitor well, located less than 100 feet from the pumped well, rose during the pumping portion of the test, again indicating a lack of vertical hydraulic continuity with the mine zone.

The Recapture Member of the Morrison Formation will provide lower containment of mining fluids. During the pumping test, the monitor well completed in the lower sand of the Westwater Canyon Member did not respond to pumping. Since the thin shale separating the upper Westwater Canyon Member from this lower thin sand creates an adequate barrier to fluid flow, then the much thicker Recapture Member will serve to contain the mining fluids to the Westwater Canyon Member.

### Horizontal Containment

Using the methodologies described for Crownpoint analytical modeling, aquifer response to the proposed HRI injection and extraction plans (Figure 19) were simulated for

## 2.3.2 Hydrologic Test

### 2.3.2.1 Introduction

A hydrologic test was conducted in April, 1991 at Hydro Resources, Inc. (HRI) Crownpoint *in situ* uranium project in McKinley County, New Mexico. This test was designed to provide the hydrologic parameters which, coupled with core and other geologic information, will allow a characterization of our proposed production horizon in terms of continuity and leakage potential. Continuity is demonstrated to ensure that future wells drilled at the perimeter of the *in situ* leach (ISL) project and completed into the Mine Zone will actually monitor the ISL mining. Although regional pump tests are of limited value to an operator for wellfield design purposes, flow tests on individual wells can be devised to provide such design information.

### 2.3.2.2 Geology

The various tables and figures for this report are organized in the following fashion. Tables which provide general information about the test and the wells are immediately after the test, in Appendix A. Following the general tables, and also in Appendix A, are the figures general to the overall test. Data specific to the individual wells are contained in tables in Appendix B and the figures and plots for those same wells are in Appendix C. The well number provides the location of the data and figures within Appendices B and C. For instance, data for well CP-2 is designated as B.2 and C.2 in the respective appendices, and for well CP-8, as B.8 and C.8.

The geology in this area has been described in detail in other reports (HRI, 1988; HRI, 1989) and will be summarized here only briefly. A stratigraphic column for the Crownpoint area is presented in Appendix A as Figure 1 (USGS, 1977). HRI's proposed production horizon is the Westwater Canyon Sandstone, which is the middle Member of the Morrison Formation (Jurassic age). Note that the term "Westwater Canyon Sandstone Member" is used interchangeably in this report with "Westwater" and "Mine Zone". The Westwater Sandstone is a poorly sorted sandstone of about 320 feet thick in the area, which hosts considerable quantities of commercially producible uranium.

The Brushy Basin Shale is the upper Member of the Morrison Formation and immediately overlies the Westwater. This shale is continuous across the area and acts as the upper aquiclude (preventing vertical fluid movement) for the Westwater. It is noted as 115 feet thick in the region (see Figure 1), but the dense clay, as determined from geophysical logs, averages about 80 feet locally. Demonstrating its suitability as a barrier to vertical migration of *in situ* leach fluids was a primary goal of this pump test.

The Dakota Formation is directly above the Brushy Basin Shale and is predominantly sandstone with some interbedded shale and siltstone. It is the first zone above the proposed production horizon with any significant permeability. Regionally, it is 160 feet thick (Figure 1), but averages about 170 feet locally. The Dakota was monitored during the pump test to ensure that it is hydraulically disconnected from the Westwater and may be designated during ISL mining as the "First Overlying Zone".

Continuing upward, the Mancos Shale Formation is immediately above the Dakota Formation and, except for the Two Wells Sandstone Member, a 700+ feet of massive shale and siltstone. The Mancos is of such thickness and extent that wells were not completed above it for monitoring during this pump test.

The aquiclude below the Westwater is the Recapture Shale, the lower Member of the Morrison Formation, and composed of about 255 feet of silt and mudstone. Like the Mancos Shale above the Westwater, the Recapture is of such thickness that wells were not drilled and completed below it. In addition, this protects the integrity of the Recapture as a barrier to downward flow of fluid in that multiple penetrations through the aquiclude are not made arbitrarily.



### 2.3.2.3 Monitor Well Preparation

A plan view of the area with locations of the pump test wells is shown in Appendix A as Figure 2. The locations of the wells completed into the Westwater Canyon aquifer were chosen for three reasons: (1) to allow characterization of the aquifer over a large region, (2) to confirm the thicknesses estimated for the upper aquiclude, especially to the north, and (3) to provide additional geologic data on the ore and individual roll fronts. Multiple observation wells, at various distances and directions from the pumped well, are required to determine the homogeneity of an aquifer through the symmetry of the pressure response and the variability of the calculated formation parameters. Figure 2 shows the locations of the older observation wells (CP-2, CP-3) and the newer monitor wells (CP-6 through CP-10) in relation to the primary pumping well, CP-5.

Various completion data are shown in Appendix A, Table 1. The older wells, CP-1 through CP-5, were drilled in 1980 and the steel casing cemented with cement baskets placed near the top of the Westwater and uncemented, slotted casing extending into the Westwater below. Wells CP-1 through CP-4 were completed with the larger diameter 10-3/4" casing since they were intended as dewatering wells for the proposed underground mine at Crownpoint (Conoco, 1982). Well CP-5 (also known as the 'Construction Water Well') was completed with smaller 6-5/8" casing and equipped with a 30 horsepower submersible pump. This well has provided water for the existing plant facility since its installation.

The newer monitor wells (CP-6 through CP-9) were drilled in 1990 and completed with 5-1/2", 14 lb/foot steel casing which was cemented from the bottom to the surface and then perforated with oil field-shaped charges, as shown in Appendix A, Table 1. Wells CP-6, CP-7 and CP-8 were opened with ten feet of perforation in each of the top, middle and bottom (but above the AA Clay) portions of the Westwater, for a total of thirty feet. Well CP-9 was completed as an individual zone well for another purpose and was not used for this test.

An attempt was made to re-complete well CP-4, and then CP-1 as a Dakota monitor well. This was done for two reasons:

1. These wells were reasonably close to the proposed pump test well, CP-5. Pumping just this one well (CP-5) then would serve two purposes of the pump test, namely, to test the continuity of the Westwater and the integrity of the overlying aquiclude in the local mine area.
2. The costs could be minimized, since the re-completion costs were considerably less than the full drilling and completion costs of a new well.

The recompletion consisted of cementing off the lower section (the Westwater) of the well and then perforating and developing the overlying Dakota. The risks associated with the recompletion of these wells were readily understood since HRI personnel are experienced in drilling and re-completing of wells in both ISL and the oil field industries. Problems did develop as anticipated. Drill pipe was lost in well CP-4 causing it to be abandoned, and the response of the Dakota in CP-1 to the usual fluctuations caused by barometric and diurnal influences was considered too poor for its use as a monitor well. As a result, well CP-10 was drilled as a twin (a nearby well) to the Westwater monitor well, CP-8, and completed into the Dakota with a thirty foot open hole section, (Appendix A, Table 1). Field representatives from the New Mexico State engineer's Office were on site during the cementing of casing for the five new wells, CP-6 through CP-10.

Each monitor well to be used in the pump test (CP-2, CP-3, CP-6, CP-7, CP-8 and CP-10) was developed using a combination of air compressors (for air jetting) and submersible pumps. Fluid levels in the wells were then monitored with Electric Handlines (also called "E-lines", "Well Sounders" and "M Scopes") and/or Steven's Chart Recorders to ensure that they responded to the ordinary barometric and diurnal fluctuations.

#### 2.3.2.4 Town of Crownpoint Water Supply Wells

The town of Crownpoint has six water supply wells, any of which may be on or off at a particular time. These water supply wells are close enough to HRI's Crownpoint Project that this on/off operation might interfere with the detailed fluid level measurements in a pump test (see Appendix A, Table 4). As a result, and in preparation for our Area Pump Test, Mr. Salvador Chavez, Environmental Coordinator at HRI's Crownpoint Project, contacted the Navajo Tribal Utility Authority (NTUA) and the U.S. Department of Interior's Bureau of Indian Affairs (BIA) in September 1990, to ask if they would share the details of the completions and production histories for the town water supply wells. They graciously provided us with the information they had at hand. Although they did not include geophysical logs, it was enough to allow a general determination of the open zones (see Appendix A, Table 2). In addition, they allowed HRI continuous access to their metering facilities so that we could compile detailed flowrate data, and judge the interference to our Area Pump Test. HRI gratefully acknowledges their cooperation.

HRI began reading the flow meters from the individual Crownpoint town water wells in late October, 1990. Initially these meters were read twice daily, in the early morning and late afternoon, except weekends. These readings were rescheduled in mid-January, 1991 (partly because of weather) to just morning. The flowrates (in gallons per minute or 'gpm') from November, 1990, through April, 1991, are shown for the NTUA wells in Appendix A, Figure 3, and for the BIA wells in Appendix A, Figure 4. Note that during this time each well produced over 80 gpm intermittently and four of the wells produced over 110 gpm. These flowrates were calculated as an average over the period between a particular meter's totalizer readings.

Transmissivity and Storage Coefficient are two aquifer parameters normally calculated from a pump test. This is usually done most easily and accurately with a single well pumping at a constant flowrate. However, several pump tests (USGS, 1977; Mobil, 1980) have already been conducted in the area of our proposed Crownpoint ISL site and the transmissivity and storage coefficient of the Westwater evaluated. As a result, HRI felt it was not reasonable to interfere with the normal operation of the Town of Crownpoint water wells during our pump test, but to concentrate instead on demonstrating the integrity of the Brushy Basin Shale, and on showing the continuity between our monitor wells.

#### 2.3.2.5 Pump Test Design

This Area Pump Test was to be conducted in either one or two phases. Phase One would be the primary investigation and would involve producing from Well CP-5 at 100+ gpm for 72 hours, followed by a build-up of the same duration, unless interference from the Crownpoint Town water wells indicated that the build-up (recovery) could be shortened. This would test the continuity between the Mine Zone monitor wells and, through the degree of pressure response, determine the quality of the overlying confining clay.

Wells CP-8 and CP-10 are twinned wells (see Appendix A, Figure 2) completed in the Westwater and Dakota, respectively. If the overlying aquiclude (Brushy Basin) was not adequately stressed in Phase One, as determined by the differences and the character of the drawdowns in CP-8 and CP-10, then Phase Two would involve producing well CP-8 while monitoring the Dakota well, CP-10.

A number of factors can substantially influence the results from a pump test. Among these are:

- interference from other producing wells (mentioned above);
- antecedent conditions (i.e., significant trends noted before and continuing through the test);
- barometric and diurnal (tidal) effects;
- quality of the data recorded.

Fluid level measurements in the monitor wells typically begin two to three days prior to the pumping phase in order to determine antecedent conditions. If considerable and predictable, these trends are then "corrected" out of the subsequent test results. Because of possible and significant interference from the Town of Crownpoint water wells, HRI planned to begin monitoring for antecedent conditions at least six days prior to pumping.

The strength of barometric and diurnal effects can also be noted from the antecedent measurements. If these effects are large in relation to the resultant drawdowns, they too should be corrected out.

#### **2.3.2.6 Pump Test Details**

Steven's Chart Recorders had been installed on a number of the monitor wells weeks prior to the actual pumping in preparation for the test. During that time, Mr. Chavez had excellent results in operating the Steven's Recorders at the 400+ feet water levels typical for the monitor wells in the area. Therefore, recorders were installed on the Mine Zone wells (CP-6, CP-7 and CP-8) and the Dakota well (CP-10). All of the recorders were converted from 8-day clocks to 24 hour. In addition, the recorders on the Mine Zone wells were geared at 1:5 (i.e., one revolution of the drum to five feet of fluid level movement) and on the Dakota well at the more sensitive 1:1 ratio.

Mine Zone monitor wells CP-2 and CP-3 were expected to have considerable drawdown while producing CP-5, so the fluid levels in those wells were measured manually during Phase One. Manual fluid level measurements were taken from specific points marked at the top of the well casing. The same E-line was used for all readings on a particular well in order to remain consistent and minimize error. Manual readings were also taken prior to installing a recorder on a well and at other times during the test when a check of the recorder seemed appropriate.

Antecedent data collection began on Thursday, April 4, 1991. Barometric pressures were measured on a recording barometer which was maintained throughout the test at the existing Crownpoint facility. The weather was poor (snow, wind) during much of the test, which was not unexpected, and various precautions had been taken, such as the construction of small sheds over some of the Steven's Recorders which were in locations unprotected from the wind.

The pump in Well CP-5 and Phase One were started at 1100 hours, April 17, 1991. The existing 30 horsepower, 18 stage, REDA submersible pump in Well CP-5 draws power from the local electric utility, providing a reliable power source and making interruption of pumping much less likely than with a portable electrical generator. Twenty-four hour coverage was provided to continuously monitor and maintain a constant pumping flowrate, to ensure that the Steven's Recorders were tracking properly in the wells and on the charts, and to take the various manual fluid levels required.

A single, three-inch McCrometer flow meter (Model MW 503), with a totalizer and gpm indicator (0 to 250 gpm), was used to measure the flowrates on well CP-5. Typically, HRI uses a double meter system which allows the test to continue if meter problems develop. However, this meter was newly purchased a few months earlier and the existing meter run was left intact rather than modifying it for a backup meter. The initial target flowrate for CP-5 was 110 gallons per minute (gpm), but the pump was not able to maintain that rate and it was lowered to 105 gpm, and finally to 101.1 gpm over the entire 72 hour drawdown period and 100.7 gpm over the last 24 hours. These rates are tabulated in Table B.5-A and shown graphically in Figure C.5-1.

Phase One proceeded as scheduled until an instantaneous power outage (or "power bump", as it is called locally) occurred at 0545 hours, 4-18-92, and caused the pump to stop. It was off for less than two minutes before being restarted at the 100-101 gpm flowrate. This was the only interruption during the 72 hour pumping period. The pump was shut off manually at 1100 hours, 4-20-91 (after 4320 minutes of drawdown), and the recovery portion of Phase One begun. Two representatives from the New Mexico Environmental Department (ED) visited the site during the drawdown of CP-5 to observe the monitor wells, equipment, personnel, and test procedures. In addition, two representatives of the NTUA (Crownpoint office) visited and observed the test.

The drop in fluid level at the Westwater monitor well CP-8, due to pumping of CP-5, was -14.21 feet (as measured; see Appendix A, Table 5). This compares to a rise in fluid level over the same period of +0.053 feet (Table 5) in Well CP-10, which monitors the overlying Dakota Sandstone. The large drawdown in CP-8 coupled with the actual rise in water level in CP-10 caused HRI to end the test at this point (as discussed above) and not proceed into Phase Two.

### 2.3.2.7 Analysis and Results

All Steven's Recorders had twenty-four hour clocks installed for this pump test, which means that twenty-four hours is required to completely track across the time scale of the chart. All charts were manually digitized into two-hour increments and input into computer files. Files were also built for the manual fluid level and flowrate readings. This data was then plotted versus time and scrutinized for obvious errors and those errors corrected or that information deleted.

Well locations were corrected for drill hole elevation to the mid-point of the Westwater Canyon Sandstone and are shown for wells CP-1 through CP-8 in Appendix A, Table 3. Since well CP-10 is shallower than the Westwater and extends to just above the top of the Brushy Basin, the correction for deviation was made to the bottom (TD) of the well. The elevations to the top of the casings for those same wells are also shown in Appendix A, Table 3. Surface locations and elevations for the Crownpoint town wells were estimated from USGS Topographic maps and are also noted in that Table. Distances between various wells, using the locations of the wells at the mid-point of the Westwater Canyon (Appendix A, Table 3), were calculated and are tabulated in Appendix A, Table 4.

The following are some abbreviations used in the various tables and plots for this report:

antec	=	antecedent;
baro	=	barometric;
corr	=	correction;
feet H <sub>2</sub> O	=	feet of water;
F.L	=	fluid levels
gpm	=	Flowrate in gallons per minute;
MSL	=	feet above Mean Sea Level Elevation;
regress	=	linear regression;
S	=	storage coefficient (dimensionless);
T	=	transmissivity (gpd/ft).

A note on the precision of the various estimates of transmissivity and storage coefficient in this analysis. The transmissivity is typically carried to four digits and the storage coefficient to three digits here. This was not intended to imply that all of those digits are significant. Although an error analysis was not undertaken, the range of the numbers themselves indicates that, at most, two digits would be significant, and in some cases, possibly just one digit. In general, the numbers were reported in this form as a matter of convenience in transferring them from the various computer programs to this report.

As discussed earlier, the primary objectives of this test were to show the degree of communication between the Westwater and the First Overlying Zone, the Dakota Sandstone; and to show continuity in the Westwater Canyon Sandstone in that monitor wells will communicate easily across our initial proposed project area. A secondary objective was to estimate the various formation flow parameters (transmissivity and storage coefficient).

Fluid levels, calculated to Mean Seal Level elevation and just prior to starting the pump in CP-5 on 4-17-91, are shown in Appendix A, Table 5. Typically, when static fluid levels and chemical water quality differ markedly for different sands or zones, the degree of hydraulic connection between them is negligible or nonexistent. As can be seen from Table 5, the beginning fluid levels in the twin wells CP-8 (Westwater) and CP-10 (Dakota) are very dissimilar, a 98.87 feet difference. In addition, the ground water chemistry (Appendix A, Table 9) from individual well water samples reveals a marked contrast in water quality (compare sodium, sulfate, TDS, conductivity) for the Westwater and Dakota aquifers. The fluid levels and water quality strongly indicate that the Dakota and the Westwater Canyon are indeed hydraulically isolated from each other. The results shown in Figures C.10-A and C.8-A and in the composite Figure 8, Appendix A, bears this out and is discussed in more detail below.

Barometric readings taken at the project site during the pump test were converted from "inches of mercury" to "feet of water" and plotted in Figure 7, Appendix A. As atmospheric pressure changes and is charted by the barograph, the water level in a well typically goes up or down by some fraction of the change in barometer. This fraction is known as "barometric efficiency". The wellbore fluid level moves in reverse to the atmospheric pressure. As the atmospheric pressure goes up (an increasing barometer), the wellbore fluid level will go down and vice versa. Note the large changes in the barometer reading in Figure 7 during the pumping of CP-5.

Figure C.10-A shows that the fluid levels in well CP-10 (Dakota) are affected considerably by the barometric, diurnal, and antecedent conditions. The measured fluid levels were adjusted and re-plotted with various fractions (barometric efficiency) times the inverse of the barometric readings and a barometric efficiency of 0.35 settled upon. This is plotted in Figure C.10-A as the curve "Corrected for Baro.". The importance of accounting for changes in barometric pressure is especially evident when considering the trend of the measured fluid levels while pumping well CP-5, as compared to the corrected levels (see Figure C.10-A).

The recurring daily fluctuations in CP-10 demonstrate the diurnal or tidal influences on the water levels. As can be seen from Figure C.10-A, these cyclic changes do not take away from the overall, upward trend of the fluid levels corrected for barometric pressure and as a result no diurnal corrections were made.

The general upward trending slope in Figure C.10-A is indicative of antecedent conditions, in other words, the continuing and outside influence on the pressure response of a well. A "best" line fit was developed using linear regression through the curve corrected for barometric changes. This "best" line fit to the antecedent rise in fluid level gave a slope of +0.022 feet/day and is plotted in figure C.10-A as "Antec. by Regress.".

The wells CP-10 (First Overlying Zone monitor) and CP-8 (completed in the Westwater) were drilled as twins and are 72 feet apart. The drawdown in well CP-8 while pumping CP-5 was substantial, at 14.21 feet (see Tables 5 & B-8, Appendix A, and Figures C.8-A and C.8-B). A composite plot of CP-8 and CP-10 on the left side and those for CP-8 on the right side of the graph. Thus, the scale for CP-10 covers 1.0 feet, while that for CP-8 covers 20.0 feet. The large drawdown in CP-8 coupled with the attendant, overall rise in fluid level and lack of response in CP-10, and the disparity in beginning fluid levels and the water qualities of the two wells show that the Dakota Sandstone and the Westwater Canyon are, for all practical expectations, separated hydrologically.

As an additional comment to the composite graph, Figure 8, note the general rise in fluid levels in CP-10 beginning about 4-8-91, and the corresponding decrease in levels in CP-8. The drop in level in CP-8 most reasonably could be attributed to pumping of the Crownpoint Town water wells, which would affect a very

large region. The coincident and opposite rise in levels in CP-10 is typical of zones hydraulically disconnected from, but vertically close to, the pumping aquifer and is called the Moordbergum or Mandel-Cryer effect.

Typically, a well not affected by pumping and which reacts strongly to barometric and diurnal fluctuations is used to develop corrections for other wells which do not respond to the pumping. In this case, with no response in CP-10 from pumping of CP-5, corrections for the various cyclic and random changes in fluid levels could be made to other wells from CP-10. This was done in the first part of the analysis for this Area Pump Test.

The pump test analysis proceeded in two parts. The first portion involved an examination of the data and calculation of the various formation flow parameters (transmissivity and storage coefficient) using data corrected for barometric, diurnal and antecedent conditions, but not modified for the interference caused by other flowing wells. Except for well CP-10, the barometric and diurnal corrections turned out to be negligible as compared to the larger corrections made for the production from the Town of Crownpoint water wells. As a result, only the second portion of the analysis is presented here and "uncorrected" in the various tables and figures of this report refers to the fluid levels "as measured", while "corrected" refers to those corrections for the Town water wells determined from computer simulation.

As noted above, the various flow characteristics for the Westwater has been estimated in other studies and was not a primary objective here. However, by investigating the influence of the producing Town water wells on the HRI observation wells, the degree of scale of those effects could be determined. Obviously, this would involve computer simulation, and selection of the best computer model for this effort had to be considered. Models were available and on hand utilizing either the Theis solution or numerical techniques (specifically finite difference) to solve the radial diffusivity equation. The single, most important difference between the solution methods for these models is that the Theis model assumes homogeneity in the system, whereas the numerical models allow the formation characteristics (transmissivity, thickness, etc.) to vary.

The Theis solution model was ultimately selected for use for the following reasons. In order to take advantage of the non-homogeneity aspect of the finite difference model, data as to the variability of the system must already be available, and then the model set up and calibrated. Over the relatively small region that this Area Pump Test was to encompass, even when including the area of Crownpoint Town water wells, the detail is simply not available and the finite difference model would run as a homogeneous system, just as the Theis solution model.

The changing flowrates of the Town water wells have to be included in any analysis. As it happened, any change in rate lingers for some time and is usually accounted for mathematically using a special technique called superposition. Thus, any model chosen would have to handle the many changes in flowrates represented by the Town water wells. The available Theis model does so and provides an immediate graphic comparison of measured versus estimated drawdowns for any combination of the producing wells. The finite difference model accounts for changing flowrates, but in a manner more unwieldy for the user.

Two other considerations led to choosing the Theis model for this study. Generally, the Theis models are much easier to set up and very fast to run and re-run. Secondly, most analyses of pump tests involve using the Theis solution and various semi-log techniques, which were developed as extensions of that theory, to solve for the formation flow parameters, and are all based on the same limiting assumptions. Even with these restrictions, these analytical methods have proven to give excellent results as to general formation flow characteristics and are used extensively even to providing the input data for finite difference/finite element models.

All analyses for the Westwater observation wells were made in the same general manner. Consequently, that method will be described in detail for one well, arbitrarily CP-7, with the similarities to other wells understood. The fluid levels for Well CP-7 from early to late April, 1991 are tabulated in Table B.7-A and plotted in Figure C.7-A.

All flowrates for the Town or Crownpoint water wells from November, 1990 through April, 1991 (see Appendix A, Tables 3 & 4 and Figures 5 & 6) and varying on a daily basis were included in the computer simulation using superposition. Also included in this model were the flowrates from Well CP-5 (Table B.5-A) and well CP-6 (Table B.6-B). In addition, for the sake of completeness, the following were included: the 124 minute flow of well CP-5 for 103.3 gpm on 2-19-91, and again for 79 minutes at 107.6 gpm on 4-1-91, as well as the 60 minute flow of CP-6 at 18.7 gpm on 4-23-91. The individual start and stop times for flowrates in the model can be set to the second.

The most prominent feature of Figure C.7-A, as well as the region of most interest, is the drawdown and recovery caused by producing well CP-5. As a result, this was the feature chosen to be history-matched and the area most closely observed during the ensuing trial and error pressure matches with the simulator. All production wells were included from November, 1990, and transmissivity and storage coefficient were varied until the best match, of the CP-5 drawdown and the other fluid level changes, occurred. A transmissivity of 2556 gpd/ft and a storage coefficient of  $1.39e-4$  (dimensionless) achieved the best results here and was plotted as the "simulation" curve in Figures C.7-A and C.7-G. The simulation was then run with only the Town of Crownpoint water wells and the resulting estimated drawdown noted as "Town Wells" on the various figures (again, Figures C.7-A and C.7-B). The estimated effect of the Town wells was then subtracted from the measured fluid levels and the "corrected" curve plotted (Figure C.7-B). Table 6, (Appendix A) contains a summary of the transmissivities and storage coefficients used to history-match fluid levels for the various Westwater monitor wells.

Figure C.7-D is the log-log Theis-type curve match for the uncorrected drawdowns in well CP-7 during the water production from CP-5. Also shown in that plot is the match of the pressure derivatives, that is, the first derivatives of both the Theis curve and the uncorrected, measured fluid levels. As can be seen from Figure C.7-D, the first derivative has a more pronounced curvature than its parent (the Theis solution) and actually reverses slope on the log-log plot. When both the Theis and its derivative curve are moved at the same time, a more firm match will usually result than with the Theis curve alone, since there is normally a much smaller area in which a fit is good for both curves, especially if the match depends on data at the later times. This technique has gained considerable popularity since 1979 and is used extensively in the petroleum industry since it provides a more certain diagnostic tool for many of the complex geologic systems normally encountered, such as double porosity, fracture, leakage dominated, and bounded (Tibb and Kumar, 1980; Bourdet *et al.*, 1983; Bourdet *et al.*, 1989; Ehlig-Economides *et al.*, 1990). There are many additional publications, and some describe extending the technique to using the pressure integral and the second derivative.

The transmissivity calculated from the curve match in Figure C.7-D is 1734 gpd/ft and the storage coefficient is  $1.37e-4$  (dimensionless). It should be noted that, although a computer was used to facilitate the curve matches presented in this report, the selection of each match was done manually. Figure C.7-E presents the log-log match to the "corrected" drawdown data for the Theis curve and its derivative over the same time period as Figure C.7-D. The transmissivity in this case is 2198 gpd/ft and the storage coefficient,  $1.54e-4$ .

A straight line at the later times in a semi-log plot of drawdown versus log of time determines the transmissivity and storage coefficient. This provides estimates of those parameters which are preferable as compared to the log-log plots discussed earlier. This is so because the number of reasonable straight lines through the later times is usually much smaller than the possible curve matches in a log-log plot and this results in a smaller range of possible transmissivities and storage coefficients from semi-log plots.

However, the proper straight line forms in a semi-log plot only after a specific, minimum time has passed, which itself is dependent on the flow characteristics of the formation. In ground water terms, the time must be such that  $u \leq .025$  and in petroleum terms, dimensionless time ( $tD$ )  $\geq 10$ . This minimum time was estimated from the log-log Theis curve matches and then shown on the semi-log plots. Linear regression was used to determine the "best" straight line fit for points with times greater than the calculated minimum time. The transmissivity was then calculated from the slope of that straight line and the storage coefficient

from the X-intercept. Figure C.7-F shows that results for the uncorrected fluid levels and Figure C.7-G for the "corrected" data (corrected for the concurrent water production from the Town of Crownpoint water wells).

Semi-log analysis of the recovery or buildup data (after drawdown has ended) is favored over that of the drawdown analysis because the recovery data is less affected by changes in flowrate of the pumping well, which might have occurred earlier, than is the drawdown data. The time on the abscissa or X-axis is replaced by a ratio of the production time to shut-in time,  $t/t'$ . Proceeding to an even more important buildup plotting technique, the Residual Drawdown curve simply takes the difference between the initial and the shut-in fluid levels and plots this on the ordinate or Y-axis. The transmissivities are then calculated from the slopes of the "best" straight lines beyond a certain minimum time, as explained earlier. This is shown for both the uncorrected and corrected fluid levels in Figure C.7-H and the resulting transmissivities noted.

The analysis as described above was identical for all of the Westwater observation wells (CP-2, CP-3, CP-6, CP-7 and CP-8). The transmissivities calculated from the various plots for those wells are summarized in Table 7 (Appendix A) and the storage coefficients in Table 8. (Appendix A)

The semi-log Residual Drawdown curve was chosen for the pressure buildup plot because it has the significant advantage of resulting in straight lines which pass through the X-axis at the origin (zero) if there are no unusual effects, either within the zone being tested or from outside influences. A number of influences might cause displacement from the zero point, but in particular, the continued depressurization from other production wells will cause a shift to the left. This provides one means of validating the corrections made earlier for the Town of Crownpoint water wells: the lines through the corrected points should fall closer to the zero point than those for the uncorrected points.

This does happen for wells CP-2, CP-6 and CP-7 (Figures C.2-H, C.6-H and C.7-H, respectively). Figure C.3-H shows the lines to be about equidistant on either side of the zero point, but both are fairly close to zero. The difference is considered to be negligible when considered the proximal location of CP-3 and CP-2 and that CP-2 showed an X-intercept of the corrected data very close to zero.

Well CP-8 (Figure C.8-H), on the other hand, also has straight lines on both sides of the zero point, but both are further from zero than for CP-3. As can be seen from Table 8, the wells with the lowest storage coefficients are wells CP-3 and CP-8, with well CP-8 about half of CP-3 and about 2-1/2 times less than the average of CP-2, CP-6 and CP-7. Considering that a line drawn from CP-5 to CP-6 (Appendix A, Figure 2) is between wells CP-3 and CP-8 and that well CP-6 has an estimated storage coefficient close to  $1.0e-4$ , it appears that the lower storage coefficient at CP-8 is a local phenomenon. Whether it extends further to the west from CP-8 is unknown.

This lower storage coefficient at CP-8 was also reflected in the computer simulations described earlier (Appendix A, Table 6). The simulations matched the most dominant feature of the fluid level curves, the drawdown caused by CP-5, and by their very nature, would most closely reflect the conditions between CP-5 and the individual observation well. If the storage coefficient used in the simulation was lower than the regional average, then the drawdown attributed to the Town wells would be too large, as would be the resulting correction, and the line in the plots, such as Figure C.8-H, would be shifted to the right. If the formation parameters (transmissivity and storage coefficient) local to the monitor wells were near the regional average, then the correction determined by the simulation would place the X-intercept on the semi-log residual drawdown plots very near to zero, as for CP-2, CP-6 and CP-7. This indicates that regionally, between wells CP-2, CP-6, and CP-7 and the Town water wells, the storage coefficient is about  $1.0e-4$ .

As a note, another simulation was run for well CP-8 with the storage coefficient doubled to  $9e-5$ . In that case, the effects of the Town wells were decreased by just over 40%, which would shift the "corrected" line in Figure C.8-H to the left and closer to the zero point.

One final set of figures was constructed for the drawdowns associated with the production from well CP-5 and are called semi-log distance drawdown plots. The drawdown for a particular time and monitor well is

plotted against the inverse of the distance squared from the pumping well. The greater the homogeneity (the less the anisotropy) of a formation, the closer the points will fall to a straight line. The lines determined from linear regression on the semi-log drawdown plots were used to compute the drawdowns at 2880 and 4200 minutes into the pumping of CP-5. This "uncorrected" and "corrected" data were then plotted as Figures 10 and 11, Appendix A.

Two times (2880 and 4200 minutes) were used to ensure that time would not drastically affect the pressure relationship of the Mine Zone monitor wells one to another, which in turn would cause Figures 10 and 11 to differ markedly from each other in overall appearance. Both figures are reasonably the same. Note that the points for CP-2, CP-3, CP-6 and CP-7 lie, generally in a straight line, indicating homogeneity between those wells. Linear regression was used to determine the "best" line fit using the points from those four wells (excluding CP-8) and the resulting transmissivities and storage coefficients are shown in Figures 10 and 11 and in Tables 7 and 8. Not surprisingly, CP-8 lies off the line represented by the other wells.

If it is assumed that the points in Figure 10 and 11 (Appendix A) are not adequately represented by straight lines, then the system is non-homogeneous. One common method of depicting such a system is with variable transmissivities that can be separated by direction to obtain maximum and minimum values which are mutually perpendicular (an anisotropic system). Such an analysis was conducted here to allow comparison of the various estimated parameters for the different systems. This method assumes a constant storage coefficient with a variable transmissivity and, as noted above, there is evidence of just the opposite at well CP-8. As a result, the values shown below are averages with and without well CP-8 included. The angle (in degrees) of the average major transmissivity is measured such that zero is to the east and increases counter-clockwise (e.g., an angle of -45 degrees would be to the southeast and +45 degrees, to the northeast).

Using the uncorrected data:

	<u>Excluding Well CP-8</u>	<u>Including Well CP-8</u>
Storage Coefficient	9.10e-5	7.93e-5
Major Transmissivity	2,453	4,039
Minor Transmissivity	1,749	1,184
Angle of Major Transmissivity	-27	-27

Using the data corrected for the Town water wells:

	<u>Excluding Well CP-8</u>	<u>Including Well CP-8</u>
Storage Coefficient	8.48e-5	7.42e-5
Major Transmissivity	4,303	5,772
Minor Transmissivity	1,959	1,526
Angle of Major Transmissivity	-9	-17

### 2.3.2.8 Conclusions

1. The Dakota Sandstone Formation is hydrologically separate from the Westwater Canyon Sandstone. This is borne out by the water quality and fluid levels of the two sands, as well as, by the negative response of the Dakota during this Area Pump Test.
2. The continuity of the Westwater is excellent across the area of the projected ISL mine. Production Zone Monitor wells will respond readily to changes within the Mine Area.
3. Transmissivity for the Westwater Canyon Sandstone, corrected for the coincident production from the Town of Crownpoint water wells, averages about 2600 gpd/ft through the area and the storage coefficient, about  $9e-5$  (dimensionless).

### 2.3.2.9 Acknowledgements

Mr. Pelizza, Environmental Manager for HRI, coordinated all aspects of this test with the various regulatory agencies and the Navajo Tribe.

Mr. Frank Lichnovsky, Senior Geologist with HRI, provided the log correlations and geological interpretations. In addition, he coordinated the drilling and recompletion work at the Crownpoint site.

Mr. Salvador Chavez, Environmental Coordinator at HRI's Crownpoint Project, had responsibility for most onsite operations:

- developing and preparing Crownpoint monitor wells;
- compiling flowrate data from the Town of Crownpoint's water wells;
- day to day data collection and data quality control.

Mr. Craig Bartels, Reservoir Engineer, prepared the pump test analysis.



of this proceeding. My education and experience as a professional hydrologist are described in my vita, which is attached as Exhibit A to my 2005 Declaration.

2. My education, experience and credentials to give this sealed addendum are set forth in my 2005 Declaration and are incorporated herein by reference.

3. The materials, documents and information I reviewed are listed in ¶ 5 of my 2005 Declaration and are incorporated herein by reference.

#### Purpose of Sealed Testimony

4. I am giving this sealed addendum to my 2005 Declaration to discuss the implications of important new information I obtained during a visit to Hydro Resources, Inc.'s ("HRI") Crownpoint, New Mexico, office on February 8, 2005. The purpose of my visit was to review records related to structural cross-sections, fence diagrams, aquifer tests, water level measurements and other data relevant to aquifer characterization and other matters at HRI's proposed Section 17, Unit 1 and Crownpoint *in situ* leach ("ISL") mining sites. My visit was arranged pursuant to provisions of a Protective Order entered into by HRI and the New Mexico Environmental Law Center ("NMELC") on January 24, 2005, and approved by the former Presiding Officer, Judge Thomas S. Moore, on January 25, 2005. See, Memorandum and Order (Protection Order Governing Disclosure of Protected Materials) (January 25, 2005). Craig Bartels was present throughout my visit and assisted me in obtaining all of the information that I requested.

#### Expert Analysis and Conclusions

5. I found many examples of relevant structure cross sections and other structural information that appeared to be authentic. I was not able to find, in my limited search, structural evidence of any fault displacements that exceeded what has already been reported in the record.

However, with regard to the area including Section 17, I did not find any additional evidence that supported HRI's claim of extensive, confining, Recapture Shale below the area. Moreover, I reviewed figure f-5 of a paper there titled "A Basin Analysis Case Study: The Morrison Formation, Grants Uranium Region" from AAPG Studies in Geology #22". This contained a regional scale, west to east, structure cross section that showed the Recapture divided into two zones. The west zone is termed "Eolian Facies of Recapture". This zone includes the longitude of Section 17. The actual line of the cross section passed a few miles south of the Section 17 site, near the planned Springstead community, but the intent of the diagram was to suggest regional patterns that extended to the north and south. I interpret this to fit in with the determinations that Dr. Lucas and I have made in our declarations, that the Recapture is not a confining unit in the places it occurs in the Section 17 area. Eolian sediments in this case generally refer to wind blown sands and some silts, none of which evolve into low permeability, confining hydrologic units.

6. In my 2005 Declaration (§§ 44-50), I discuss deficiencies in a pump test conducted by HRI at the Crownpoint mining site in April 1991. I testified that because of those deficiencies, the test could not have detected communication between the Westwater Canyon Aquifer and the overlying Dakota Sandstone Aquifer. The implication of the pump test being designed and implemented improperly and the results misinterpreted is that HRI could not demonstrate that mining fluids would be confined in the Westwater Canyon.

7. In § 49 of my 2005 Declaration, I state that HRI offered no explanation for why an observation well had been located so far from the pumping well used for this test. I stated that several explanations are possible. One possibility is that the well was placed far enough away from the pumping well to ensure that no drawdown would be observed. Another is that

differential scouring of the Brushy Basin created zones of interconnection near and to the east of the pumping well, but not to the west. I was interested in the details of the fates of two initial Dakota monitor wells, CP-4, and CP-1. The record stated that CP-4 was abandoned due to lost drill pipe problems, and that CP-1 was abandoned due to poor barometric efficiencies.

8. I reviewed construction information for Dakota test well CP-4. I did not find any information that contradicted HRI's description in the record.

9. I then reviewed water level data for test well CP-1, which is also completed in the Dakota Sandstone. I did not confirm the HRI claims of "barometric inefficiency" for that well. I also found water level data for that well, monitored as late as March 20, 1991, only a month before the April 1991 pump test. The water level data I reviewed for this well and its location appear to be new information never before assessed in this case.

10. CP-1 is located next to a Westwater test well, CP-2. As I indicated in ¶ 48 of my 2005 Declaration, CP-1 was installed to take the place of CP-4, which was a Dakota observation well that had been installed 500 feet east of the pumping well for the test, CP-5. CP-4 was abandoned shortly after being drilled because of a "lost drill pipe." The locations of most of these test wells are shown on Figure 2.3-3 in the Crownpoint Project In Situ Mining Technical Report, June 12, 1992 (HRI, 1992b at 33). However, CP-1 and CP-4 are not shown on Figure 2.3-3.

11. During the test, CP-5 was pumped, and the resulting decreases in water levels were monitored in all of the observation wells. Two sets of wells are of interest for this discussion. Each set, or pair, consists of two wells relatively close to each other. One well is only completed in the Dakota and one is only completed in the Westwater. CP-1 (Dakota) and CP-2 (Westwater) on the east and CP-8 (Westwater) and CP-10 (Dakota) on the west. A

distance of about 2,000 feet separates the observation well “pairs”, and both pairs are located about 1,000 feet (one on the east, and one on the west) from the pumping well — a distance that is at least 20 times greater than standard practice in conducting pump tests.

12. Since the time interval was relatively small between the measurement at CP-1 and the measurements at the other wells, this supports a valid comparison.<sup>1</sup> Note that the CP-1/CP-2 pair of wells is approximately 2,000 feet to the east of the CP-8/CP-10 pair. Given this information, I prepared Table 3, which compares the relative water levels in these wells in an equivalent fashion.

**Table 3. Comparison of Water Levels Just Prior to April 1991 Pump Test at HRI Crownpoint Site.**

Well	Formation screened	Approximate water level (feet above mean sea level)	Water level difference between Dakota and WCA at well location (ft)
CP-10	Dakota	6573 (April 17)	98.4
CP-8	WCA (twin to CP-10)	6474.6 (April 17)	
CP-1	Dakota	6547 (March 20)	83.0
CP-2	WCA (twin to CP-1)	6464 (April 17)	

13. Notably, both aquifers are sandstones and show a trend of water-level decline due to the pumping from both aquifers by the Crownpoint municipal wells to the east. The decreasing differential between the two aquifers cannot be attributed solely to the municipal pumping, which affects both aquifers more or less equally. Instead, the table shows a more revealing decline — the decline in the water level *difference* between the two aquifers over that 2,000-foot distance. The difference of 15.4 feet is significant. It is strongly suggestive of an increased hydraulic interconnection between the Dakota and the WCA in the area of the CP-1/CP-2 well pair. In general, there appears to be a corresponding trend with regard to

<sup>1</sup> Moreover, the cited pump test report contains several hydrographs, such as Figure C.2A, which shows that water levels at CP-2 only fluctuated by approximately 6 feet over the 9 days prior to the test.

potentiometric (water level) differences between the Dakota and the WCA. The difference is distinct at Unit 1, where the water levels in Dakota wells can be nearly 200 feet higher than the water levels in the WCA wells. However, that difference drops to only 100 feet at CP-10, which is roughly 2.5 miles closer to the town of Crownpoint and its municipal water supply wells. This trend, along with the other information discussed above, supports the possibility that there is indeed a degree of hydraulic communication between the Dakota and the WCA somewhere to the east of well CP-5, in HRI's Crownpoint mining unit. The most logical place, therefore, to have placed a Dakota monitoring well would be at the east end of HRI's Crownpoint site.

14. In summary and conclusion, the April 1991 pump test at the Crownpoint mining site could not accurately determine if the Dakota is or is not in hydraulic communication with the WCA in the region of the WCA pumping well. Moreover, important facts detailing shortcomings of the test were left out of the description found in the FEIS (at 3-29) and in HRI's various responses to the NRC Staff's questions about Westwater-Dakota interconnection. The additional information about hydraulic trends that I reviewed in HRI's files supports a conceptual model of increasing hydraulic communication between the two aquifers from west to east. The most conclusive evidence of aquifer interconnection (or lack thereof) during the CP pump test would have come from the eastern end of the site, near CP-1. The water levels at CP-1 do not appear to exist in the record, although this information was found in HRI's records. HRI is knowledgeable about relative water levels between aquifers, and their implications to the planning of pumping tests to determine interconnections.

15. This concludes my testimony.

Pursuant to 28 U.S.C. § 1746, I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 3rd day of March 2005.

A handwritten signature in cursive script, reading "Michael G. Wallace". The signature is written in black ink and is positioned above a horizontal line.

Michael G. Wallace, MS