



Denison Mines (USA) Corp.
1050 17th Street, Suite 950
Denver, CO 80265
USA

Tel : 303 628-7798
Fax : 303 389-4125

www.denisonmines.com

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VIA PDF AND FEDERAL EXPRESS

Mr. Rusty Lundberg
Co-Executive Secretary
Utah Water Quality Board
State of Utah Department of Environmental Quality
195 North 1950 West
P.O. Box 144850
Salt Lake City, UT 84114-4850

Dear Mr. Lundberg:

Re: Stipulated Consent Agreement UGW09-03 dated January 27, 2009; Nitrate Contamination Investigation Report, White Mesa Uranium Mill Site, Blanding Utah dated December 30, 2009; and letter dated October 5, 2010 from the Executive Secretary

Reference is made to the Stipulated Consent Agreement UGW09-03 dated January 27, 2009 (the "Consent Agreement") related to nitrate contamination at Denison Mines (USA) Corp's ("Denison's") White Mesa Uranium Mill Site, near Blanding Utah (the "Mill"), and to the *Nitrate Contamination Investigation Report, White Mesa Uranium Mill Site, Blanding Utah*, dated December 30, 2009 (the "CIR") submitted to the Utah Division of Radiation Control ("DRC") pursuant to Item 6.A of the Consent Agreement.

Reference is also made to the letter dated October 5, 2010 from the Executive Secretary of the Utah Radiation Control Board/Co-Executive Secretary of the Utah Water Quality Board (the "Executive Secretary") notifying Denison of his determination that the CIR has not fully satisfied the Consent Agreement requirements (the "DRC Notice").

The purpose of this letter is to summarize the additional studies identified to date that may be addressed in a revised CIR, including the additional studies suggested in the DRC Notice, any proposed additional studies relating to the new information introduced by Denison at a meeting held on October 26, 2010 between Denison and DRC staff (the "October 26 Meeting"), and any other additional studies that Denison believes may be relevant. This letter also proposes a date for a meeting between DRC Staff and Denison technical and regulatory staff to discuss the foregoing studies and any associated matters, to agree on the studies to be performed and the manner of performing those studies, and to develop a plan and schedule for performing such studies and for submittal of a revised CIR.

1) Additional Studies Suggested in the DRC Notice

In the DRC Notice, DRC suggested a number of additional studies that could be performed in support of a revised CIR. DRC's observations and suggestions are discussed below.

a) Nitrate Source Determination (Frog Pond)

DRC concluded that Denison's conclusion in the CIR that the source of the nitrate/chloride contamination was likely from use of Frog Pond water is "unsubstantiated with direct and reliable evidence" and suggested a number of additional studies that could be performed in order to substantiate this conclusion, including the following:

i) *Blanding City Wastewater Discharge to the Frog Pond*

DRC concluded that Denison has offered no quantifiable data to support any contamination from the City Lagoon to the Frog Pond, and that additional information and sources to support these claims are required in order to substantiate these claims.

ii) *Demonstration of Slug Flow Behavior*

DRC concluded that "*no clear slug behavior is evident to the DRC, as claimed in the CIR, since Nitrate and Chloride concentrations downgradient from the Mill are within the range of upgradient concentrations. The statements by DUSA regarding slug flow behavior need further explanation by DUSA, and need to be justified by sufficient data and analysis*"

DRC proposed that such additional work should include but not be limited to the following additional studies:

- Additional wells and borings around the Frog Pond;
- Hydraulic evaluation including equipotential data utilizing additional testing around the Frog Pond;
- Characterization of any ground water mounding potentially caused by the Frog Pond
- Geologic Information;
- An evaluation of the elevation of the Brushy Basin shale upper contact in the area of Coral Canyon and an interpretation of the hydraulic conditions between the Frog Pond and the Mill Site;
- Additional Nitrate + Nitrite (as N) and Chloride shallow ground water quality data for new upgradient wells installed near or around the Frog Pond area; and
- Additional characterization to determine the presence and location of a preferential ground water flow path that allowed a 30 year or less nitrate travel time from the Frog Pond to the Mill Site.

iii) *Hydraulic Gradient and Flow Path Issues*

DRC concluded that Denison has not offered analysis of potential ground water hydraulic paths from the City Lagoon to the Frog Pond (e.g., has not mapped local stream tubes), and that the arguments in the CIR based on flow velocities from upgradient sources to the current plume location were "inconclusive and indicated that assumptions of preferential flow paths and heterogeneities would be needed to explain the observed plume location, however, the claims of preferential flow paths were not studied or supported." DRC did not recommend any particular studies that could be performed.

b) Need for Additional Source (Potential Multiple Source) Investigation

DRC noted that the CIR provided some "limited justification" that certain sources identified in the Source Review Report contained in the CIR could not be the sole sources of the plume concentrations based on low contributions of nitrate, time of use, etc. However, DRC concluded that it is not appropriate to negate these sources (e.g., the SAG leach field) without additional assessment as recommended in the Source Review Report. DRC noted that such additional assessment should include the following:

- In-situ soil sampling; and
- Shallow ground water sampling.

c) Potential Option for Additional Study/Justification for an "Upgradient" Source

DRC also noted that, in order to distinguish an "upgradient source", Denison may opt to perform isotopic analysis to provide information regarding an "upgradient" contaminant signature (isotopic fingerprint) to confirm that the same signature is present at multiple locations and depths both beneath the Mill and at "upgradient" locations. DRC also noted that the study should also include an evaluation of "downgradient" nitrate concentrations at multiple locations and depths.

2) Additional Studies Proposed by Denison

After reviewing DRC's recommendations and suggestions in the DRC Notice, and considering other possible studies identified by Denison, Denison proposes that the following additional studies be undertaken to form the basis for a revised CIR.

a) Additional Studies Relating to Frog Pond as a Potential Source

It is clear from the DRC Notice that DRC does not believe the nitrate/chloride contamination at the Mill site could have originated from the Frog Pond.

Denison's conclusions in the CIR relating to the Frog Pond and the City Lagoons are based on anecdotal evidence and on assumptions that historical practices at the City Lagoons may have resembled practices followed by other similar facilities across the country in the past, which practices have resulted in nitrate and chloride contamination to groundwater at a number of those facilities. However, as has been observed at such other facilities, groundwater contamination may have been caused by historical practices that are no longer being followed, and it is therefore very difficult to determine the source of the contamination, based on currently available information. This fact, combined with the fact that Denison does not control the land near the Lagoons and the Frog Pond and cannot mandate that the current owners participate in any field investigations, has resulted in Denison not recommending the pursuit of the additional studies recommended in Section 1(a) above at this time.

Denison believes that information relevant to the potential sources of contamination that may be identified in the studies discussed below may provide additional evidence that could warrant pursuit of additional investigations relating to the Frog Pond in the future. However, at this time, Denison believes it is better to direct its resources at some of the other avenues discussed below.

b) Additional Source (Potential Multiple Source) Investigation

i) *Geoprobe study*

Denison proposes to perform a geoprobe study of unconsolidated soils in areas at the site that could have had a large enough potential nitrate or chloride source and a large enough hydraulic head to potentially have reached the perched groundwater zone at the site, as identified in the Source Review Report that was included in the CIR. Samples will be collected at 6 to 10 foot depths from such specific potential sources and analyzed by the synthetic precipitation leaching procedure (SPLP) (EPA Standard Method 1312) for nitrate and chloride. Denison will propose to DRC a plan and schedule for carrying out this study, including the potential areas to be included in the study.

ii) Shallow Groundwater Sampling

Denison believes that the nitrate and chloride plumes are sufficiently characterized from the existing monitoring wells placed in the perched aquifer. Therefore, Denison is not proposing that any additional wells be drilled at this time. However, the isotopic sampling and analysis discussed in paragraph (d) below will be performed at selected existing monitoring wells at the site, which may provide additional useful shallow groundwater sampling information.

iii) Mass Balance Analysis

Denison also proposes that it would be beneficial to carry out a mass balance analysis. Such an analysis will analyze the concentrations of nitrate and chloride in the groundwater, the hydrogeologic features associated with the plume, any mounding of water in the perched zone or lack thereof and other relevant factors, and determine the concentrations or amounts of nitrate and chloride that would be necessary in order to generate the concentrations identified in the plume. Denison believes that such an analysis will provide useful information in eliminating certain potential sources from further consideration and could possibly identify new potential sources.

iv) Supplemental Historic Source Study

Denison proposes to extend the existing Source Review Report to address or further evaluate existing and new potential sources, such as the military installation/ordinance source that was located near the Mill, and any overlooked ranching sources.

c) Investigation of Potential Natural Reservoir of Nitrate and Chloride in Soils Beneath the Mill Site

At the October 26 Meeting, Denison mentioned the possibility that the nitrate and chloride contamination at the Mill site and in surrounding areas may be caused by a large reservoir of bioavailable nitrogen and chloride that has been observed to have been accumulating in subsoil zones of arid regions over time. Attached to this letter is an article entitled *A Reservoir of Nitrate Beneath Desert Soils*, dated November 7, 2003, written by Walvoord et al, that addresses this concept. In that article, the authors note that "[r]ecent studies indicate that subsoil NO₃ reservoirs are readily mobilized to groundwater when desert land is converted to irrigation. . ." and that "[d]am construction or changes in climate and vegetation could likewise mobilize subsoil nitrate reservoirs, with local to regional effects."

Denison was not aware of this potential source of the nitrate and chloride contamination at the time it submitted the CIR to the Executive Secretary.

Denison proposes to undertake a coring study to determine if such a phenomenon exists at and around the Mill site that could have caused or contributed to the nitrate and chloride contamination under investigation. This study would test the possibility that a reservoir of nitrate and chloride exists at some level in the geologic column above groundwater due to lack of distributed recharge to groundwater over an extended period of time.

Core would be taken from an area that has not been affected by focused recharge such as the wildlife ponds or intermittent streams and drainage channels. Samples of core would be taken at regular intervals, moisture content measured, and leached with specific amounts of double distilled water to determine the concentrations of nitrate and chloride present in soil moisture. Mass balance calculations would then integrate the mass of nitrate and chloride in soil moisture to determine if the total mass is sufficient to account for the observed concentrations in groundwater. Denison will propose to DRC a plan and schedule for carrying out this investigation.

d) Additional Study/Justification for an "Upgradient" Source

The DRC Notice suggests that studies be aimed at identifying possible "upgradient" sources. However, it should be noted that any additional studies should also be aimed at identifying sources not related to Mill activities, which need not be upgradient sources.

Denison agrees that stable isotopic analysis may be employed to distinguish different sources of nitrate contamination that may distinguish one or more sources that are not related to Mill activities.

Denison proposes to perform such an analysis at the Mill site to identify the isotopic fingerprint of the nitrate contamination. This may provide information that will be useful in determining if the nitrate contamination is due to one or more sources that are not related to Mill activities. This study will include an evaluation of upgradient and far downgradient contamination.

Denison will propose to the Executive Secretary a plan and schedule for carrying out this investigation.

3) Suggested Date for Meeting

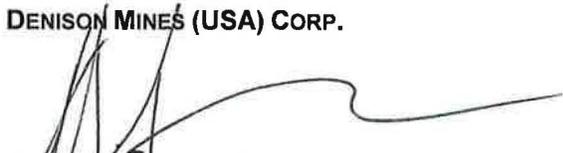
Denison proposes that DRC staff meet with Denison technical and regulatory staff on November 30, 2010 to discuss the additional studies Denison proposes to undertake, as summarized above, and any other investigations DRC and Denison may identify. If that date does not work, Denison would be pleased to accommodate DRC's schedule.

It is hoped that at the meeting DRC and Denison will agree on a proposed course of action in general terms, including the objectives of each study and the criteria that must be satisfied in order for DRC to consider the revised CIR to meet all applicable requirements. Denison will, within two weeks of the meeting, submit detailed plans and schedules for each additional study to be undertaken, for Executive Secretary approval.

If you have any questions or require any further information, please contact the undersigned.

Yours very truly,

DENISON MINES (USA) CORP.


David C. Frydenlund
Vice President, Regulatory Affairs and Counsel

cc: Ron F. Hochstein
Harold R. Roberts
Jo Ann S. Tischler
David E. Turk
Daniel W. Erskine, Ph.D. INTERA, Inc.

Yungay area, the nature of the oxidant remains unexplained. Photochemical reactions initiated by sunlight continually produce oxidants in the lower atmosphere and surface. However, in most soils, biological production of reduced organic material completely dominates the net redox state of soils. When biological production is less than the photochemical production of oxidation, then the soil will become oxidizing. The transition from biologically dominated soils to photochemically dominated soils appears to be abrupt. Whichever process dominates will shift the redox state in one direction or another. In the Atacama, there is a gradual decline in biological activity as conditions became drier, yet near the extreme arid region there is an abrupt transition to very low bacterial levels and low organic content.

It is unlikely that the oxidizing conditions are due to high ultraviolet flux, because the site is only 1 km above sea level. Instead, the dry conditions in the Atacama must inhibit biological production of reductants and possibly enhance the survival of photochemically produced oxidants. Our results suggest that in the extreme arid core of the Atacama, we have crossed the dry limit of microbial survival in extreme environments. The net result is that photochemical processes dominate. Thus, in the Atacama Desert, we find almost no microorganisms and low levels of organic material, and the organic material present appears to have been oxidized. The LR experiments confirm the presence of as-yet-undefined oxidants in the Atacama soil. In many respects, these soils are similar to the Mars soils investigated by the Viking Biology Experiment and may provide a valuable testing ground for instruments and experiments designed for future Mars missions.

References and Notes

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9. Rain and temperature data for Chile are available from Dirección Meteorológica de Chile at www.meteochile.cl. Climatological data for Chile from 1912 to 1970 are available at http://docs.lib.noaa.gov/rescue/data_rescue_chile.html.
10. Materials and methods are available as supporting material on Science Online.
11. S. A. Benner, K. G. Devine, L. N. Matveeva, D. H. Powell, *Proc. Natl. Acad. Sci. U.S.A.* **97**, 2425 (2000).
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14. We acknowledge support from NASA's Astrobiology Science and Technology for Exploring Planets program and Biomolecular Systems Research Program, the National Autonomous University of Mexico (grant nos. DGAPA-IN119999 and IN101903), the National Council of Science and Technology of Mexico (grant nos. 32531-T and F323-M9211), the NASA-Ames/Louisiana State University Cooperative Agreement (grant no. NCC 2-5469), the National

Science Foundation (award no. DEB 971427), and the University of Antofagasta.

Supporting Online Material
www.sciencemag.org/cgi/content/full/302/5647/1018/DC1
 Materials and Methods
 SOM Text
 Figs. S1 and S2
 Data Tables S1 to S6

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A Reservoir of Nitrate Beneath Desert Soils

Michelle A. Walvoord,^{1*} Fred M. Phillips,² David A. Stonestrom,³
 R. Dave Evans,⁴ Peter C. Hartsough,^{5,6} Brent D. Newman,⁷
 Robert G. Striegl¹

A large reservoir of bioavailable nitrogen (up to ~10⁴ kilograms of nitrogen per hectare, as nitrate) has been previously overlooked in studies of global nitrogen distribution. The reservoir has been accumulating in subsoil zones of arid regions throughout the Holocene. Consideration of the subsoil reservoir raises estimates of vadose-zone nitrogen inventories by 14 to 71% for warm deserts and arid shrublands worldwide and by 3 to 16% globally. Subsoil nitrate accumulation indicates long-term leaching from desert soils, impelling further evaluation of nutrient dynamics in xeric ecosystems. Evidence that subsoil accumulations are readily mobilized raises concern about groundwater contamination after land-use or climate change.

Increased deposition of bioavailable nitrogen (N) at the land surface has adversely affected water quality, biodiversity, and ecosystem functioning around the world (1–6). Understanding such impacts requires quantification of N sources, reservoirs, and cycling rates (1, 5, 7, 8). Desert soils, which cover approximately one-fourth of the conterminous United States and one-third of the land surface worldwide, are reportedly low in total N (9, 10). Studies of N cycling in terrestrial ecosystems have traditionally examined only the biologically active soil zone, defined operationally as extending to ~1 m in depth (9, 11). Within this zone, N turnover is rapid (6), and N concentrations decrease with depth (7, 10, 11). Natural sources of N in desert ecosystems include nitrate (NO₃⁻) and ammonium (NH₄⁺) in precipitation, eolian deposition of nitrate salts, and biological assimilation of atmospheric N₂ by N-fixing organisms (5, 7, 8, 10). Mechanisms of N removal include

plant uptake, volatilization to ammonium and other gases, wind erosion, and denitrification (6, 7, 12). Nitrogen loss from the soil zone by leaching is generally assumed to be negligible in desert ecosystems (5, 10, 12). Our findings challenge this assumption, demonstrating that substantial quantities of N, as NO₃⁻, have leached and accumulated beneath the soil zone over millennial time frames.

Soil-water N generally follows a nutrient-type profile, with concentrations that decrease sharply with depth because of biological uptake and cycling (11). In contrast, soil-water chloride (Cl⁻) follows a conservative solute-type profile, with concentrations that increase with depth because of progressive evaporation and water extraction by plant roots. In desert settings, Cl⁻ typically exhibits an exaggerated conservative solute-type profile resulting from the accumulation of thousands of years of atmospheric Cl⁻ deposition (13). A recently developed model (14) (supporting online material) quantitatively explains these Cl⁻ profiles by considering geothermally driven water vapor transport toward the atmosphere, together with the hydraulic sink created in the soil by the roots of desert plants. Physical and biological processes selectively remove water, concentrating Cl⁻ (Fig. 1A).

Surprisingly, soil-water concentration profiles of NO₃⁻ N in five arid-to-semiarid sites in the western United States (Fig. 2) (15) follow the conservative solute-accumulation profiles of Cl⁻ (Fig. 3) rather than the expected progressive nutrient depletion profiles. Maximum NO₃⁻ N

¹U.S. Geological Survey, Lakewood, CO 80225, USA.

²Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, Socorro, NM 87801, USA. ³U.S. Geological Survey, Menlo Park, CA 94025, USA. ⁴School of Biological Sciences, Washington State University, Pullman, WA 99164, USA. ⁵Graduate Program of Hydrologic Sciences, University of Nevada, Reno, NV 89557, USA. ⁶Desert Research Institute, Reno, NV 89512, USA. ⁷Earth and Environmental Science Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA.

*To whom correspondence should be addressed. E-mail: walvoord@usgs.gov

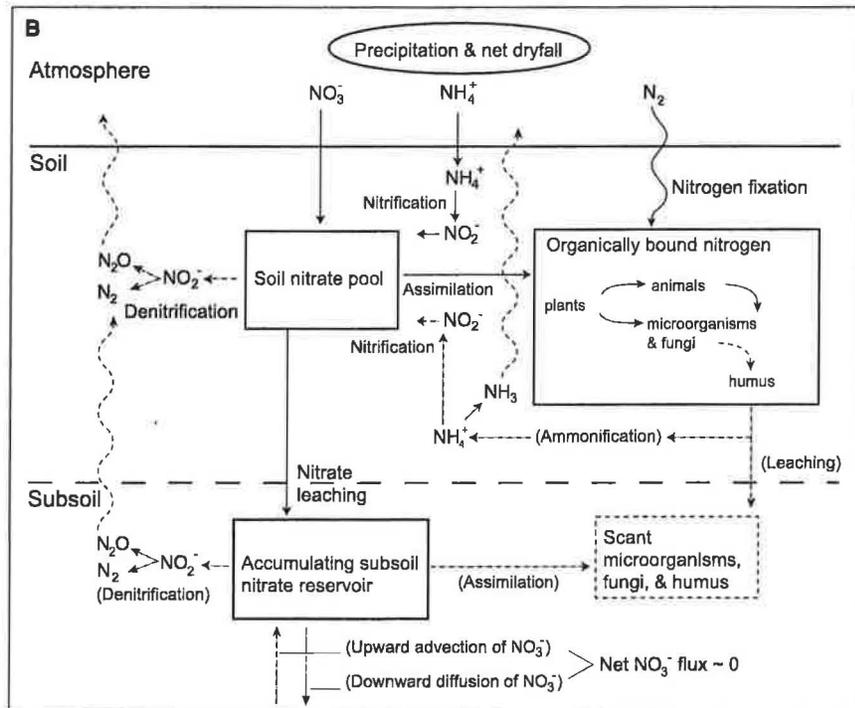
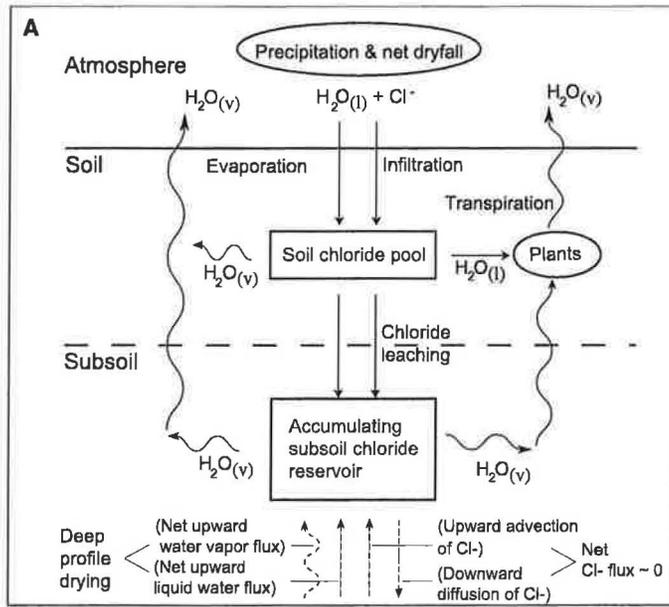


Fig. 1. Main transformations and transport pathways for water, Cl^- , and NO_3^- in desert systems. Straight lines denote liquid (l) pathways; wavy lines denote vapor (v) pathways; dotted lines denote minor pathways. **(A)** Water and Cl^- pathways. Cl^- arrives at the land surface in dust and precipitation, accumulating near the land surface (soil Cl^- pool) during normal conditions of limited rainfall separated by prolonged droughts. Conservative Cl^- anions are completely excluded from soil vapor and preferentially excluded by cell membranes from plant transpiration. Soil Cl^- leaches to the subsoil reservoir during infrequent major wetting events. Water returns to the soil zone and atmosphere as vapor, leaving nonvolatile Cl^- behind. Small net fluxes of water and Cl^- beneath the upper subsoil are directed upward, reflecting deep-profile drying under current climatic conditions. **(B)** NO_3^- pathways. NO_3^- acts like Cl^- with respect to leaching and exclusion from soil vapor. Unlike Cl^- , however, NO_3^- is preferentially taken up by plants and is reactive. Assimilation, nitrification, denitrification, and ammonification are all biologically mediated. Subsoils, beneath the root zone, are virtually devoid of organic matter and active organisms, where leaching and evaporative concentration are the main processes affecting NO_3^- . Soil-pool flushing after extended dry periods, when limited bioavailable carbon reserves are exhausted, leaches accumulated NO_3^- to the subsoil below the reach of plants.

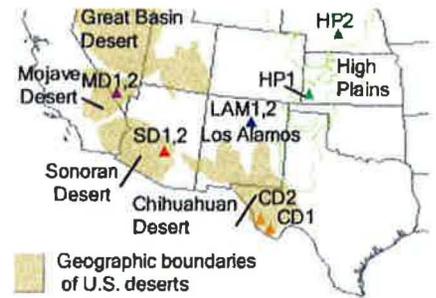


Fig. 2. Map showing locations of vadose-zone pore-water concentration profiles used in this analysis.

concentrations in the subsoil below these nutrient-limited vegetation communities (10) can exceed $2000 \text{ mg liter}^{-1}$, surpassing N concentrations applied in hydroponic agriculture by a factor of 10. Clearly, not all NO_3^- N is consumed in the soil zone. We infer that NO_3^- , like Cl^- , leaches from the soil pool to the subsoil reservoir, just beyond the reach of roots, during occasional deep-wetting events. Once there, NO_3^- concentrates as water moves upward as vapor along energy gradients and ultimately returns to the atmosphere via plants (Fig. 1B). The sustained absence of downward water movement below the subsoil reservoir has enabled NO_3^- to accumulate for thousands of years (13, 14). Desert subsoils are persistently low in organic matter, low in microbial populations, low in water content, aerobic, and neutral to basic in pH (16); all of which promote NO_3^- stability and inhibit denitrification (17).

Integration of the NO_3^- N profiles from 1 m to the maximum depth sampled yields subsoil NO_3^- N inventories that vary from 30 to $13,600 \text{ kg of N ha}^{-1}$ (table S2). The NO_3^- N inventories show high intra- and interregional variability relative to Cl^- inventories. This is not surprising, as N gains and losses within the soil zone are controlled by unevenly distributed plant and microbial activity, in addition to hydraulic controls (Fig. 1B). Despite the large variability, general trends are apparent. For example, the pinyon-juniper woodland in semiarid northern New Mexico (Los Alamos) has the lowest NO_3^- N inventory, suggesting a lower limit for environmental conditions under which subsoil NO_3^- N accumulates in appreciable quantities. A nearby ponderosa pine woodland that receives moderately more rainfall shows little to no subsoil NO_3^- N accumulation (18).

One key factor contributing to contrasting NO_3^- behavior in arid and humid soils is the establishment of a persistent hydraulic sink at the base of the soil zone in deserts. Cl^- mass balance calculations provide an estimate of the time scales over which conditions required for solute accumulation have been maintained (13, 14) (supporting online text). Estimated accumulation times for the desert sites range from 10,000 to

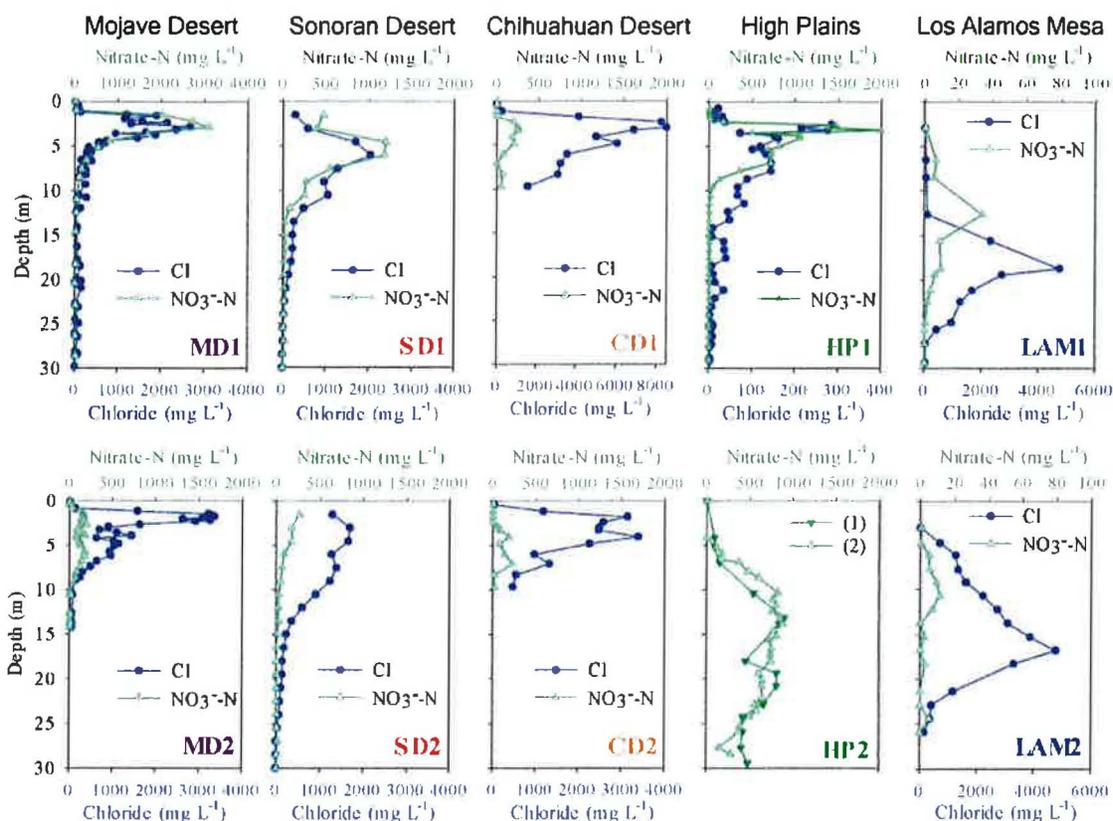


Fig. 3. Vadose-zone nitrate-N and chloride pore-water concentration profiles from locations indicated in Fig. 1. (No chloride data are available for HP2.) Note the change of the Cl (bottom) scale for CD1, HP1, LAM1, and LAM2 and the change of the NO₃⁻-N (upper) scale for MD1, LAM1, and CD2. Data sources are as follows: MD1 (74), MD2 (29), SD1 and SD2 (30), CD1 and CD2 (37), HP1 (32), HP2 (27), and LAM1 and LAM2 (33).

16,000 years (table S2). These accumulation times are consistent with the hypothesis that the onset of arid Holocene climatic conditions and succession to xeric vegetation (19) triggered subsoil solute retention (13, 14, 17). Although the presence of biochemical pathways makes NO₃⁻ transport much more complex than Cl⁻ transport (Fig. 1), the strong similarity of the two profiles at many sites (Fig. 3) suggests that subsoil input histories, transport behavior, and accumulation times are similar. In the sampled environments, inferred subsoil NO₃⁻-N retention times exceeded the 3000-year soil organic N pool maximum retention time (9) by as much as a factor of 5.

Comparisons of subsoil inventories to soil inventories for the sampled regions (7, 10, 12) as well as for arid-to-semiarid soil inventories worldwide (9) indicate that subsoil N (as NO₃⁻) inventories are similar in magnitude to total soil N inventories (Fig. 4 and table S2). Based on these comparisons, subsoil NO₃⁻-N likely accounts for a preponderance of total vadose-zone N (ground surface to water table) in nonriparian arid environments. The ratios of subsoil NO₃⁻-N to total vadose zone N are 44 to 92% for the Mojave Desert, 41 to 81% for the Sonoran Desert, and 41 to 62% for the High Plains region. Subsoil NO₃⁻-N accounts for ~4 to 20% of the total vadose zone N in the Chihuahuan Desert and <4% in dry forests similar to the Los Alamos sites. Assuming that comparable inventories (1 to 5 kg ha⁻¹) exist in the 3 × 10⁹ ha of Earth's warm deserts and arid

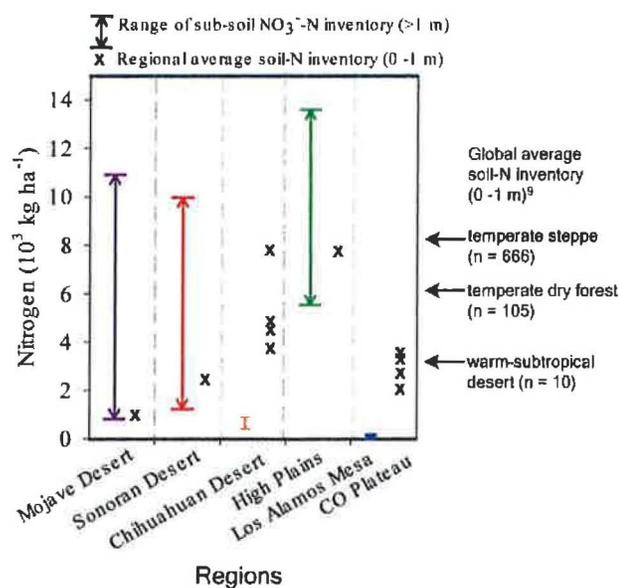


Fig. 4. Comparison of subsoil NO₃⁻-N inventories (table S2) with average regional and selected global soil N inventories. Multiple soil N regional averages correspond to average measurements collected under different species. Sources for soil N data are as follows: Mojave and Sonoran Deserts (10); Chihuahuan Desert (34); High Plains (35); and CO Plateau (7, 36). Los Alamos data are compared with CO Plateau data based on similar vegetation, proximity, and lack of local soil N data.

shrublands, subsoil NO₃⁻-N inventories contain approximately 3 to 15 Pg of bioavailable N. This compares to global total estimates of 21 Pg in desert soils and 95 Pg in all soils (9). Consideration of subsoil NO₃⁻-N thus raises estimated global inventories of vadose-zone N by 14 to 71% for desert regions and 3 to 16% overall. Reducing uncertainty in these estimates will require substantial sampling efforts, given

the variability among measured profiles. Nevertheless, the large amount of subsoil NO₃⁻-N indicated by all of the sites warrants consideration in assessments of global as well as arid-land N distributions.

The indicated leaching of soil NO₃⁻-N to the subsoil reservoir affects long-term N cycling calculations that derive fluxes from residuals. For example, estimates of N lost to the atmosphere by volatilization and denitrification will

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be inflated by the amount of NO_3^- N leached to the subsoil; the latter is substantial at some of the sites investigated. Averaged over Cl⁻-based accumulation times, long-term NO_3^- N soil losses via leaching to the subsoil reservoir range from 3×10^{-3} to 6.8×10^0 kg of N ha⁻¹ year⁻¹ (table S2). For comparison, mean annual inorganic N in wet deposition (NO_3^- N plus NH_4^+ -N) ranges from 0.8 to 4 kg of N ha⁻¹ year⁻¹ in the western half of the United States (20). Our data do not permit precise generalization of NO_3^- N soil leaching to subsoil reservoirs. Even so, NO_3^- N soil leaching clearly constitutes an appreciable fraction of atmospheric N deposition over large areas.

Leaching of N from arid soil zones is unexpected, given the N-limited nature of desert ecosystems and the high nutrient utilization efficiency of xeric plants (10, 21, 22), and cannot be readily explained. The presence of large quantities of NO_3^- N sequestered below a depth of 1 m demonstrates that not all of the available NO_3^- N is consumed in the soil zone or returned to the atmosphere. Ecologic implications follow, given the strong linkages between nutrient cycling and plant community dynamics. Recent studies show that desert plants do not necessarily take up water and nutrients simultaneously (23). In addition, some species may rely solely on available N at the soil surface (24). Such behaviors may help explain the apparent paradox of NO_3^- N leaching from soils populated by N-limited vegetation.

Subsoil NO_3^- reservoirs also have implications for groundwater quality, as their mobilization may adversely affect public water supplies. Drinking water exceeding the maximum contaminant level established by the U.S. Environmental Protection Agency of 10 mg of NO_3^- N liter⁻¹ is associated with methaemoglobinemia, miscarriages, and non-Hodgkin's lymphoma (3, 25). Investigations in the 1970s reported large amounts of subsoil NO_3^- in southern California (26) and central Nebraska (27) that could not be attributed to agriculture or other human activities. Similarly, investigations of high NO_3^- levels in Las Vegas Valley groundwater near irrigated fields ruled out fertilizer, livestock, and septic systems as sources of pollution (28). Recent studies indicate that subsoil NO_3^- reservoirs are readily mobilized to groundwater when desert land is converted to irrigation (29) (fig. S3). Dam construction or changes in climate and vegetation could likewise mobilize subsoil nitrate reservoirs, with local to regional effects.

References and Notes

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African Droughts and Dust Transport to the Caribbean: Climate Change Implications

Joseph M. Prospero^{1*} and Peter J. Lamb²

Great quantities of African dust are carried over large areas of the Atlantic and to the Caribbean during much of the year. Measurements made from 1965 to 1998 in Barbados trade winds show large interannual changes that are highly anticorrelated with rainfall in the Soudano-Sahel, a region that has suffered varying degrees of drought since 1970. Regression estimates based on long-term rainfall data suggest that dust concentrations were sharply lower during much of the 20th century before 1970, when rainfall was more normal. Because of the great sensitivity of dust emissions to climate, future changes in climate could result in large changes in emissions from African and other arid regions that, in turn, could lead to impacts on climate over large areas.

Aerosols, including mineral dust, can affect climate directly by scattering and absorbing solar radiation and indirectly by modifying cloud physical and radiative properties and precipitation processes (1). Over large areas of the Earth, the atmospheric aerosol compo-

sition is dominated by mineral dust. Dust storms and dust plumes are the most prominent, persistent, and widespread aerosol features visible in satellite images (2). Dense dust hazes often cover huge areas of the Atlantic, Pacific, and Indian oceans down-