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Air Pollution and Desert Systems at Risk: The Susceptibility of Pothole Ecosystems on the Colorado Plateau to Acid Deposition

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Abstract. Potholes are ephemeral rain pools in rock. These pools contain an aquatic fauna unique to temporary environments. Some species found in potholes are related to organisms that have been shown sensitive to reduced pHs. The ability to neutralize added acids, or buffering capacity, is low in potholes. These qualities indicate that potholes may be at risk from acid deposition. Results from this study show that while pothole water has low alkalinity, sediments in the basins have buffering capacity that can be mobilized to neutralize added acids. More study is needed to determine the extent of this buffering. Chemical analyses of pothole water in and near Arches National Park show little evidence of pollution. These findings indicate that pothole ecosystems studied are not at risk from acid deposition at this time. Pools nearer pollution sources on the Colorado Plateau, and potholes in non-calcareous rocks, should be studied to determine if these systems are good candidates for biomonitoring.

Introduction

Acid deposition in the arid Southwest has received little attention in the past for a number of reasons. Sources of acidic pollutants are not as concentrated as in the eastern United States. Pollutants were thought to be diluted and dispersed during scarce and infrequent precipitation events in deserts. The alkaline soils of the Southwest have high buffering capacity, and most surface and ground waters are alkaline (Roth et al., 1985). Any acidic deposition in the Southwest was thought to be quickly neutralized, preventing damage to desert organisms.

These generalizations do not hold for all ecosystems in arid and semi-arid parts of the Southwest. *Acidic pollutants may actually accumulate over time via dry deposition. During a small precipitation event, the resultant solution could be much more acidic than the rainfall itself.

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Specific desert systems (e.g., potholes, cryptogams, desert mountain aquatic systems) may not have the buffering capacity of surrounding rock and soil, and thus may be at risk to damage from acid deposition.

The Southwest is dotted with power plants and industrial facilities that add pollutants to the atmosphere. The Colorado Plateau region, of particular interest for this study, is surrounded by coal- and oil-fired power plants (Figure 1), and new sources are likely over the next 20-50 years. Wind patterns carry air masses from industrial areas (e.g., Southern Arizona and Mexican smelters, the Los Angeles Basin, etc.) across the Colorado Plateau (Malm and Joseph, 1985). NADP stations on or near the Colorado Plateau (Figure 1) have recorded pHs of less than 5 for many weekly precipitation averages in the past eight years, the lowest being 3.84 at Mesa Verde National Park for the week of 30 August 1983 (NADP/NTN, 1989).

Aquatic organisms are particularly susceptible to decreased pHs (Arvola et al., 1986; Ormerod et al., 1987; Pierce and Sikand, 1985; Weatherley and Ormerod, 1987). Research on sensitivity to acid deposition should include studies of aquatic systems predicted to be at risk. Biomonitoring can then be used to indicate changes in precipitation chemistry.

Potholes are depressions in bedrock that are not in active drainages. Precipitation collected in these basins creates small, ephemeral aquatic environments. These pools contain fauna unique to temporary aquatic systems. Some organisms inhabiting potholes are related to species known to be sensitive to decreased pH (Sprules, 1975; West, 1980; Schindler and Turner, 1982; Eilers et al., 1984; Keller and Pitblado, 1984; Pierce and Sikand, 1985; Stokes et al., 1989). Alkalinity measurements in potholes have generally been low. Changes in pH would be more rapid in potholes in response to acid rain than in other aquatic systems in the Southwest. For this reason potholes are good candidates for biomonitoring acid deposition rates in the Southwest.

A study was initiated in 1988 to answer some of the questions concerning sensitivity of pothole ecosystems to acid deposition. Research focused on two areas: basic ecological questions of pothole species, community structure, and ecosystem functioning, and sensitivity of pothole species and systems to acidification. Acid sensitivity studies included three areas: 1) sensitivity of individual species' reproduction to low pH, 2) bioassays of pothole organisms to determine whether any species can be used as biomonitors, and 3) in situ acidification of potholes. Chemical analysis of precipitation collected in potholes was conducted periodically during the study. Potholes included in the study are in Navajo Sandstone in Arches National Park, and Grand Resource Area, Moab District, Bureau of Land Management, Utah.

Ecology of Potholes

Few studies have been made of pothole ecology on the Colorado Plateau (Romney, 1971; Findley, 1975; Dodson, 1987). Environmental tolerance ranges are unknown for most species inhabiting Colorado Plateau potholes, as are hatching and mating cues. Little is known about determinants of community structure, what drives ecosystem functions, or what roles potholes play in surrounding terrestrial ecosystems. Before we can assess the impacts of air pollution on potholes, we need to learn more about the basic ecology of pothole species, communities, and ecosystems.

Characterization of pothole basins and communities were conducted in 1988. Over 120 potholes have been examined, and more than 80 were used in parts of this study. Surface areas and volumes were estimated, and surface area/depth and surface area/volume ratios calculated to

categorize the physical environment of the basins. Pool size (=longevity) has been reported to structure pothole communities (Dodson, 1987). The range of volumes are shown in Figure 2.

Species composition was determined periodically during 1988 in a qualitative manner. Quantitative sampling was done in 1990. Season and random precipitation patterns appeared to be the primary factors influencing occurrence. Some groups, such as copepods and the ostracod Cypridopsis sp., were present in great numbers in May and early June, but were absent from the same pools in the summer. They reappeared in late September or October, 1988. Copepods were present in fall of 1989 and 1990, but Cypridopsis has not been observed since 1988. Aquatic insects were generally less common in 1988 than in previous years.

Community respiration/production was measured in 1989 in a few pools by measuring dissolved oxygen at dusk-dawn-dusk for three days. Smaller pools appeared to be heterotrophic (O_2 content dropped over time), while larger pools experienced an increase in O_2 . Precipitation was too low to repeat this experiment using more pools to test the generality of the 1989 results.

Sensitivity of pothole species and systems to acidification.

Potholes appear to be more susceptible to acid deposition than most desert aquatic systems (Dodson, 1991). Effects of low pH on ephemeral rock pools should be studied now, as these will probably be among the first systems affected by increasing pollution levels in the Southwest. Pothole communities and/or individual pothole-dwelling species may make good biological indicators of increased acid deposition. In order to use these systems in this capacity we need to know how they respond to lowered pHs.

- A. Sensitivity of individual species' reproduction to low pH. Response to lowered pH varies among species, age classes, and type of response (Bell, 1970, 1971; Schindler, 1980; Confer et al., 1983; Pierce, 1985, 1987; Watras and Frost, 1989). Adults of many aquatic species may be able to tolerate quite low pHs, but reproduction and/or larval development may be seriously affected at higher pHs (Hendrey et al., 1976). Studies of impacts of acid deposition should include efforts to determine the effects of lowered pH on egg production, fertilization, egg hatching, and larval development.

Eilers et al. (1984) state that amphibians, mollusks, and leeches are groups that are most sensitive to acid conditions. Amphibian egg and larval development at low pHs were examined to determine the sensitivity of these stages to acidification. Because toads and frogs use external fertilization, both sperm and eggs are exposed to low pHs in acidified waters. Thus, there is a greater opportunity for impacts of low pH on reproduction in amphibians (Pierce, 1985). The opportunistic breeding behavior of the species inhabiting potholes (Bufo punctatus and Scaphiopus intermontanus) makes it almost impossible to examine the effects of low pH on fertilization itself. Studies were conducted on the effects of acid on hatching of fertilized eggs, and on early larval development.

Hatching success of ephemeral pool crustaceans in acid solutions was studied by adding different H_2SO_4 solutions to dry pothole sediment. Numbers of tadpole, fairy, and clam shrimp, and ostracods were counted after 24 hours. Results indicate a trend toward reduced hatching at lower pHs. Fairy shrimp and tadpole shrimp showed the strongest response. Clam shrimp and ostracods hatch more slowly, and it was difficult to get enough of these taxa to generate a pattern of sensitivity or resistance.

Response of these species to acid solutions is affected by interactions between solution and sediment. Acid solutions used in the hatching experiments were buffered by the sediment--pH of solutions increased by as much as 2 pH units in 5 hours (Graham, 1990). Buffering occurs within the time that hatchlings were first observed in the above experiments. I do not know whether the weak response to the acidic solutions is due to rapid buffering, or because these species are relatively acid tolerant. Experiments are needed where the pH remains constant at each treatment level.

The sediment-solution reaction appears to provide a measure of protection for pothole systems from acid deposition. Acidic precipitation falling on potholes in Navajo Sandstone would probably be buffered before organisms became active and thus susceptible to lowered pH conditions. Additional work is needed to determine the mechanism involved in the buffering interaction. A cation and anion analysis of pothole sediments should show what chemical species could be acting as buffers.

- B. Bioassays of pothole organisms to determine whether any species can be used as biomonitors. Sensitivity to increased acidity can be very precise for many aquatic organisms (Eilers et al., 1984). Monitoring presence/absence, population shifts, and/or shifts in community structure of sensitive species can be used to indicate degradation of the pothole environment. Bioassays can determine which species will make good biomonitors (Cairns, 1983; Kimball and Levins, 1985).

Considerable work has been done on sensitivity of aquatic species in eastern North America (e.g., Schindler, 1988; Stokes et al., 1989; Vangenechten et al., 1989), but little has been done in western North America (Roth et al., 1985; Corn et al., 1989; Harte and Hoffman, 1989). Three types of bioassay studies of pothole organisms will be done: a) LC_{50} tests of adult crustaceans and snails, b) LC_{50} studies of crustaceans, using newly hatched larvae, and c) measurements of metabolic heat production by pothole inhabitants under different pH conditions in a microcalorimeter.

1. Bioassays of adult crustaceans and snails will be done to determine LC_{50} pH levels for each of the major macroinvertebrate species in potholes. These studies will provide information on how these species would be affected if an acidic precipitation event occurred after previous rains had filled the potholes, and the organisms had been active for a week or more. The pH gradually increases in a pothole over time after a rain. There is little chance that a precipitation event that occurred a week or more after initial filling would be acidic enough to drop the pool pH to the experimental levels (e.g., pH 5.0 or 4.5). These bioassays are useful, however, in determining which species are sensitive to acidic conditions. Some of these species (e.g., Bufo punctatus, Triops longicaudatus, Fossaria sp.) are common throughout the Southwest. The LC_{50} data can be used to identify potentially sensitive species in areas receiving more acidic precipitation and with less buffering capacity available in sediments and rock.
2. Similar bioassay studies will be done on newly hatched crustacean larvae, amphibian embryos and larvae, and gnat larvae. Many species show increased sensitivity to low pHs in early developmental stages (Pierce 1985, 1987; Schindler et al., 1985; Watras and Frost, 1989). In pothole systems, it would be possible for invertebrates to begin hatching, and amphibians to breed in response to a small rain event of normal pH, and then be inundated by a large volume storm dropping

acidic precipitation. This could drop the pH of the pool rapidly, affecting eggs and larvae of sensitive species. These studies will help identify species that are susceptible to acid deposition from such a scenario.

3. Measurements of metabolic heat production from pothole organisms in acidic solutions will be made. A microcalorimeter (Hansen et al., 1989) will be used to measure metabolic response of pothole organisms to reduced pHs. A slight shift in pH may not be fatal, but could stress the organism, affecting metabolic rate. One of three general responses is expected: metabolic rates will increase, decrease, or remain unchanged.

The pothole environment has a short-lived wet phase. Pothole organisms must be able to survive the dry pothole environment in some way, and to develop rapidly during the wet phase to the stage that can survive the dry pothole (e.g., egg, adult leaves dry pothole, etc.). Metabolic rates of pothole inhabitants have not been measured, but it is predicted that rates for most species will be high because of the need to grow rapidly to complete life cycles before the pools dry up.

Changes in metabolic rate in response to lowered pH can have drastic effects on reproduction. If metabolic rate is reduced, time needed to reach maturity and reproduce will increase, perhaps requiring more time than is available before a given pool dries up. An increase in metabolic rate could occur if the organism responds to damage from acidic water by repairing the damage. Metabolic activity and resources would have to go toward repairs rather than growth and reproduction, again increasing development time. Metabolic rate studies are needed, as are growth rate studies under different pH solutions.

- C. In situ acidification of potholes. Behavior of species under controlled conditions may be quite different from responses under natural conditions (Cairns, 1983; Kimball and Levins, 1985; Likens, 1985; Brezonik et al., 1986; Carpenter et al., 1989). For example, Eilers et al. (1984) found in their extensive literature review that in laboratory studies minimum pH tolerances were one pH unit or more lower than field studies with the same taxonomic groups.

To assess how pothole ecosystems respond to acidification, nine potholes were acidified, three each to pH 5.5, 5.0, and 4.5. Each pothole was studied for 6 days before acidification; pH, alkalinity, and temperature were measured at three locations in each pool three times each day, and pool volume and invertebrate populations were estimated once each day. Where possible, total number of tadpole shrimp were counted in each pool. An additional three pools were studied but were not acidified, to act as control pools. The same data were collected from all 12 pools following acidification until the pools dried up (four days).

Potholes that were acidified had pHs return to near normal within 24 hours of acidification, probably as a result of buffering by sediment. Despite this rapid return to normal conditions, at least tadpole shrimp and fairy shrimp populations experienced significant mortality (Graham, 1990). Mortality of clam shrimp and ostracods was also observed, but significant differences between pre- and post-acidification populations were not measured. Dipteran larvae and pupae (Culicidae and Ceratopogonidae) did not appear to be affected by acidification.

Chemical analyses of pothole water collected shortly after rains fell in 1988 and 1989 have shown remarkably low levels of heavy metals and other elements that would indicate the air was not carrying a significant pollution load. These results, in conjunction with the finding that pothole sediment may play an active role in buffering added acids, may mean that Colorado Plateau potholes are not at a high risk from acid deposition at the present time. Further study is needed to determine the potential for future risk. Research is also needed to examine pothole ecosystems and communities in other National Park units, such as Glen Canyon and Lake Mead National Recreation Areas, which are closer to pollution sources (Navajo and Mojave Generating Stations, respectively), and Joshua Tree National Monument, where the pollution load is greater, and the buffering capacity may be lower because of different rock types.

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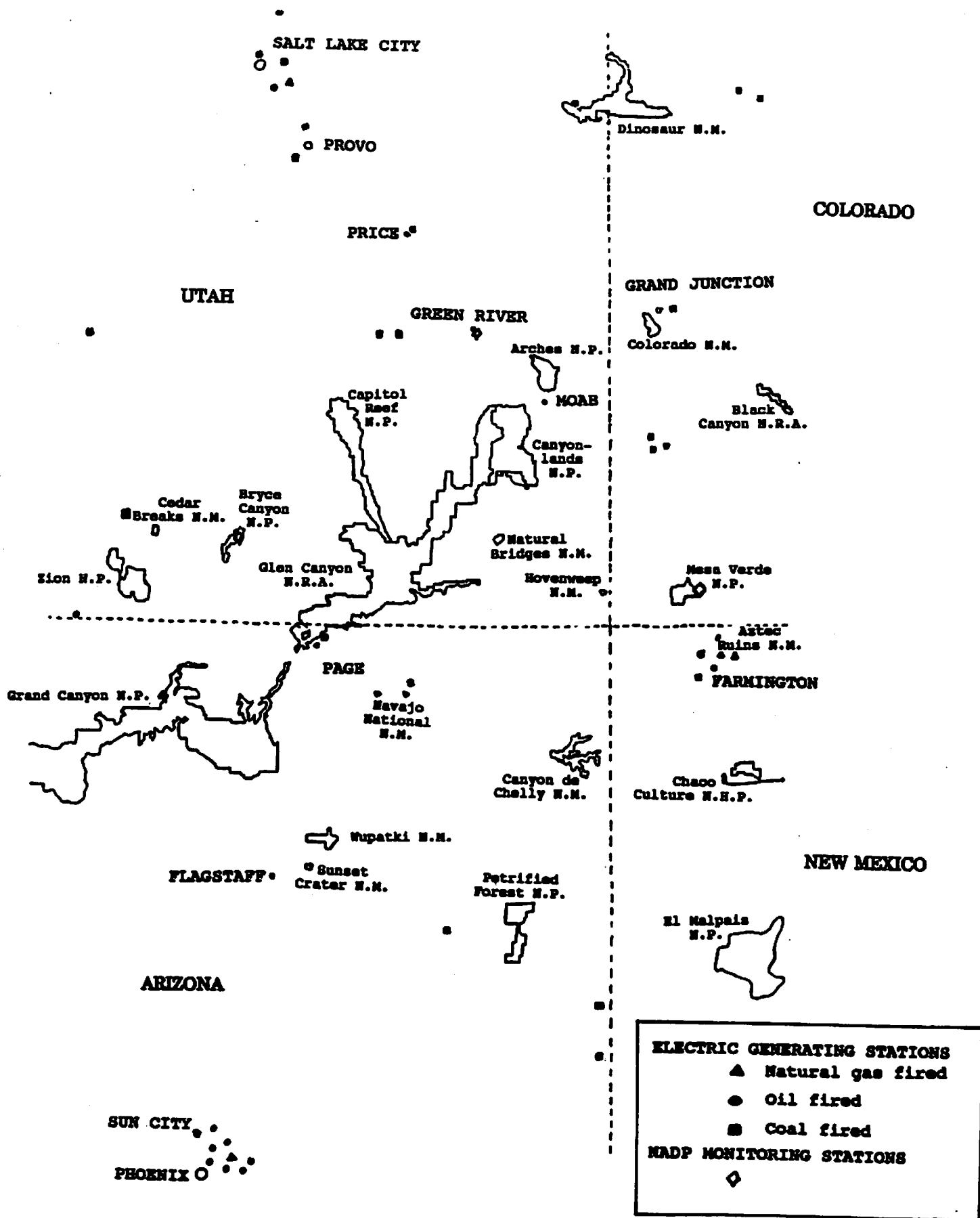
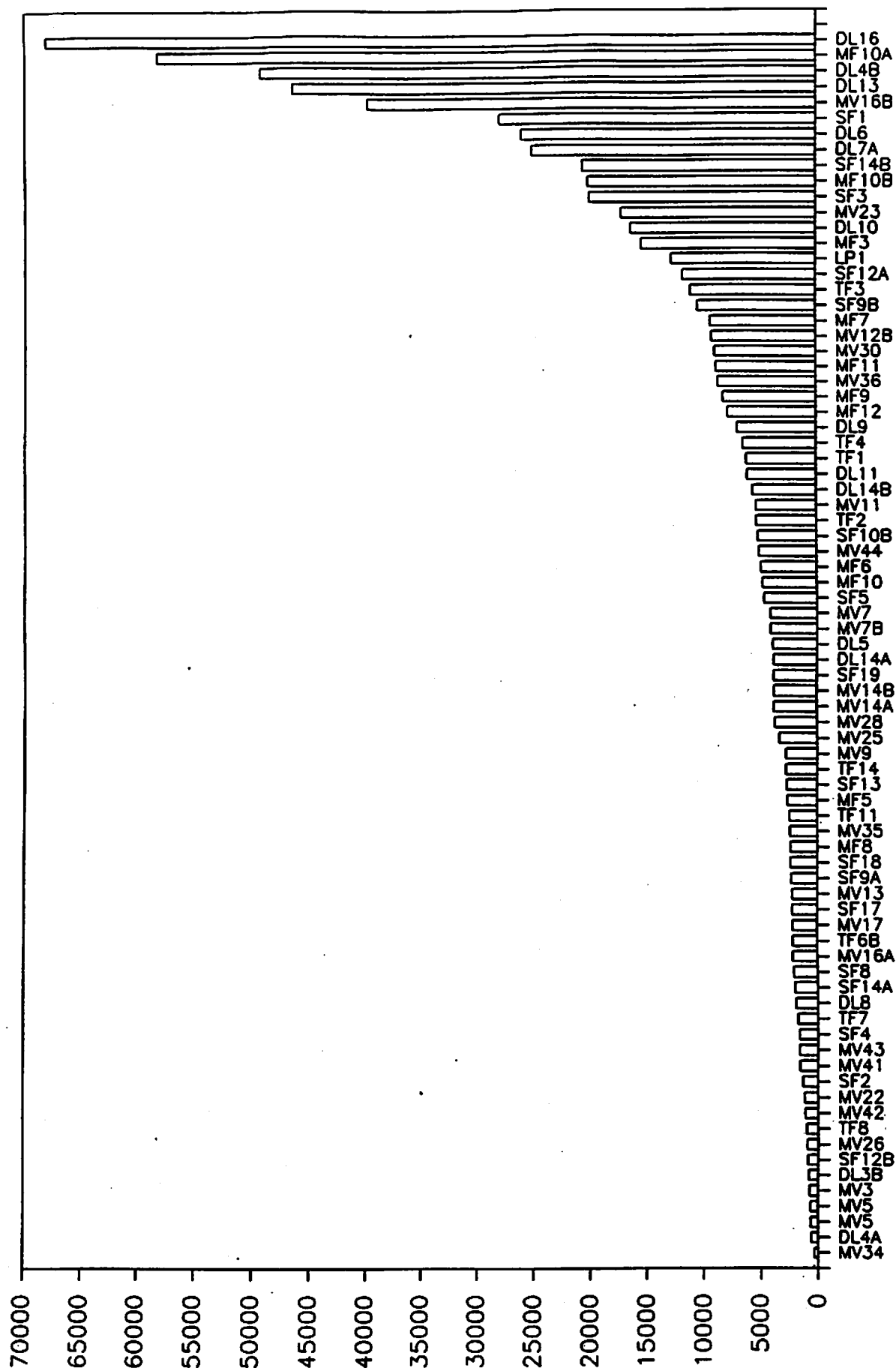


Figure 1. National Park Service units, electric generating stations, and NADP monitoring stations on or near the Colorado Plateau. Map information compiled by Jayne Belnap.

Figure 2. Estimated pothole volumes (liters) for 79 potholes in or near Arches National Park, Utah.



Pothole names