

DRAFT Hydrologic Assessment of the Cliff Palace Area
Mesa Verde National Park
Michael Martin, January 1996

Introduction

In the Fall of 1995, Park staff at Mesa Verde National Park (MEVE) observed water seeping from a rock shelter and wetting one of the largest and most visited cliff dwellings in the park, Cliff Palace. While moisture in this area is not unprecedented, it is by no means a regular occurrence, and poses a significant threat to the structural integrity of the cliff dwellings. The Water Resource Division (WRD) was contacted by Park staff and requested to perform a hydrologic assessment to determine the cause of the seepage and suggest possible strategies for remediation.

The purpose of this report is to identify probable causes of wetting at Cliff Palace and illustrate that the seepage is most likely derived from water use activities on the mesa top. ~~Furthermore it is the intent of WRD to provide Park staff with a hierarchy of remediation actions. To accomplish both of these objectives a comprehensive summary of both the hydrogeologic system and the water use activities will be presented, and a general water budget will be established for the Cliff Palace area. The conclusions are not unequivocal because some uncertainty exists in many of the observations and estimates; however they should be considered the most plausible based on existing data.~~

The scope of this report is primarily concerned with the Cliff Palace area because this is where moisture is presently threatening existing dwellings. Additionally, two other areas, Chapin Mesa and Wetherall Mesa were visited, but for the sake of brevity these areas will be covered in a supplemental document.

Setting

Mesa Verde National Park is located within the Colorado Plateau geologic province. The park terrain is characterized by high mesas and deeply incised canyons. The drainages follow a linear dendritic pattern that trends principally north-south. This configuration is suggestive of landscape evolution in predominantly horizontal to slightly sloping sedimentary strata with minor structural control (Ritter, 1986). The Mancos River, which flows perennially, is approximately three miles south-southeast of, and one thousand feet lower than Cliff Palace. All the tributary canyons within the park, including the one below Cliff Palace, flow only in response to rainfall, indicating the regional water table is below the canyon bottoms.

The mean annual precipitation, calculated from the 72 year park record is 18.32 inches. The average wettest month is August,

followed by July and March with mean precipitation values of 2.08, 1.81, and 1.78 inches, respectively. The average driest month is June with a mean precipitation of 0.64 inches. The greatest annual precipitation from 1923 to 1994 occurred in water year 1941 (Oct.1940-Sept.1950) with 30.44 inches, and least in water year 1977 (Oct. 1976-Sept.1977) with 7.83 inches.

The entire rock unit in the vicinity of Cliff Palace is the Upper Cliff House Sandstone member of the Mesa Verde Group (J.H Irwin, 1966), which is a Cretaceous age, near-shore marine deposit that is near horizontal, dipping about seven degrees to the south (Griffitts, Pers. Comm., 1996). The lithology varies from interbedded sand and siltstone to massive sandstone forming characteristic slopes and ridges, respectively. A case-hardening rind is present on sub-aerial surfaces of the sandstone and desert varnish is apparent on many of the ridge sides.

All of the strata that enter into this discussion are part of the Upper Cliff House Sandstone, however for the purpose of this hydrologic analysis, ~~it is convenient to subdivide this unit into~~ three distinct beds based on lithology and resulting differences in hydrogeologic properties. The lowest exposed unit in this area is a roughly 100 foot section of interbedded sandstone-siltstone deposits. Overlying that is the sandstone layer where the majority of the dwellings were constructed. This sandstone is a fine grained, massive, quartz arenite with calcium carbonate cement, about 100 feet thick. Overlying this massive sandstone is a relatively thin (about 26 feet) layer of interbedded sandstones and siltstones (Griffitts, Pers. Comm., 1996).

Hydrogeology

Both the overlying and underlying sandstone-siltstone beds likely act as aquitards impeding vertical infiltration of water. This is evidenced in the lower unit by observed seeps and springflow near the contact with the overlying massive sandstone, and numerous areas of evaporative deposits. In the overlying sandstone-siltstone unit, rejection of leach field effluent at two different sites demonstrates the low permeability of these beds. Vertical permeability in the massive sandstone layer is relatively high, although thin layers of silt and clay may locally reduce the rate of infiltration. The rock shelters that were utilized by native dwellers likely were formed from ground water sapping at the base of the massive sandstone.

Regardless of the varying permeabilities of the different rock units, the dominant factor controlling infiltration of surface water is likely the presence of vertical joints. The principal vertical joint pattern trends roughly north-northwest to south-southeast and are about 50 to 75 feet apart. Additionally there are a series of joints roughly perpendicular to the primary joints,

although these are more widely spaced. Horizontal joints also exist along presumed bedding planes and lithologic transitions. Within the rock shelter itself, three distinct vertical joints were observed, all with evidence of previous wetting in the form of desert varnish. The farthest joint from the shelter opening was actively transmitting water and appeared to be the primary source of moisture in the rock shelter at the time of the visit.

Water in the Shelter

Substantial wetting was most recently observed in Cliff Palace shelter on November 12, 1995. While moisture in the shelter is not unprecedented, it had never been observed at this time of the year, and this magnitude of seepage has only been recorded once in this location. In the month of April sometime prior to 1982, {it would be useful to know the exact year} a large quantity of water was observed seeping into the rock shelter. Protective actions similar to those presently used were taken to minimize impact on the dwellings. ~~Active seepage continued into early summer and the area remained moist throughout the next season.~~

The present seepage was first noticed in November of this year. According to park staff, that was likely close to the time that it began. During the spring season of 1995, moisture was observed in the rock shelter, ~~however no dripping water and no soaking of the dwellings occurred.~~ By the end of November, roughly twelve separate rooms or areas in the center portion of the shelter were exposed to significant moisture dripping from the ceiling which soaked these areas. Some of these dwellings still have original plaster. At the time of this writing, water is actively dripping from several locations of the ceiling.

Evidence of prior moisture in the shelter is recorded throughout this century. In 1912 Superintendent Shoemaker requested money be set aside to repair damage in Balcony House and Cliff Palace caused by rockfall and seepage. Moisture was blamed for the partial collapse of an unspecified kiva in 1943. Seepage was reported as a major problem in the Painted Tower section in 1946 leading to the suggestion of drain installation. In 1948, kiva "W" needed repair of a bulging wall caused by seepage, and a large section of the shelter floor collapsed due, apparently to ground water sapping. Also in that year, seepage was threatening a flat arch section of the secondary ledge and two tons of wet sand were removed from the top of the arch.) In response to these events, 35 feet of perforated drain pipe was installed at an unrecorded location; however, this did not completely alleviate the moisture problem. There exist additional references to seepage and moisture in both 1952 and 1960 (Horn, 1988).

In 1960, a United States Geological Survey (USGS) geologist recommended construction of a drainage tunnel behind Cliff Palace

bentonite

at the contact between the massive sandstone and the underlying sandstone-siltstone aquitard. Such a tunnel would intercept groundwater flowing toward the rock shelter and redirect flow away from the dwellings. Construction was begun in June of 1961 and completed in August of the same year. The tunnel had a total length of about 300 feet and was apparently very effective in eliminating seepage from the northern part of the Cliff Palace. Examination of the tunnel indicated that it was actively intercepting a substantial quantity of water at the time of the site visit (Dec.1995), and that this water was apparently more concentrated in the vertical joints. Apparently, a substantial volume of water has been pervasive through time because numerous stalactites approaching a length of one inch, and thick deposits of travertine have formed within the tunnel.

An analysis of the rainfall record was conducted to determine which periods were the wettest and how these compared to recorded episodes of seepage. The two episodes that were of particular interest were the most recent and the pre-1982 event which are ~~similar in magnitude and location. Recognizing that precipitation~~ is a cumulative phenomenon, cumulative two and three year annual totals were calculated. The wettest recorded period was in the late 1930's and early 1940's. This is possibly the reason that there are numerous references to seepage in the 1940's. The second wettest period apparently was in the mid 1980's around 1986-87, but ~~there are no known references to seepage at this time. The recent~~ period of 1993-94 had similar totals to the 1986-87 period. Two year totals from the early 1980's were close to those of the recent period, but three year totals from the early 1980's were markedly below the recent period. While it appears that different series of wet years roughly correspond to wetting episodes in the shelter, this is by no means absolute. The wet period in the mid 1980's, which occurred at a time when seepage likely would have been noticed and recorded, did not result in apparent seepage at the shelter.

1978-79
wet

There is little doubt that at least some of the incidences of wetting in the past are of natural origin. Rock shelters of this type are commonly formed by groundwater sapping. The presence of numerous springs and evaporite deposits at the same stratigraphic level of the floor of Cliff Palace indicate that this is a natural groundwater discharge zone. However, given the fact that these structures have been abandoned for about 700 years, and the presence of moisture can severely impact the integrity of this type of architecture, it is very unlikely that the dwellings have been subjected to frequent wetting events during their history. Furthermore, geologic or botanical indicators of frequent wetting in the form of desert varnish and established flora were not observed in the areas presently impacted. The late season occurrence of the present event coupled with the magnitude and location of the seepage, strongly suggests that the source is not natural. One alternative source that must be considered in detail

is water released on top of the mesa related to visitor service facilities.

Mesa-Top Activities

In the early 1960's, considerable visitor-use infrastructure was emplaced on the mesa overlying Cliff Palace. A number of these structures have the potential to affect both the amount of water on the mesa, and the timing and location of both natural and anthropogenic runoff. Elements of particular concern are a dead-end water line that requires periodic draining and is also subject to developing leaks, the presence of a leach field that services a comfort station, a parking lot that redirects runoff, and a ditch which may concentrate natural and anthropogenic runoff in an undesirable area.

The water supply on top of the mesa is provided by a 2-inch diameter, four mile long water line. The operation of the water line has undergone some changes in the last few years that have necessitated bleeding of the line to maintain a chlorine residual acceptable to public health standards. Additionally, at the end of the season the entire line is drained into the ditch, which adds water to the bleeding operation. A final important fact regarding the water line is that it was constructed in a non-uniform manner from "available material" and is prone to leaking. A substantial leak was discovered in 1994 and repaired. The following season evidence of a leak in the form of saturated ground was also observed but no repairs were made. {additional ref, to leaks would be helpful}

The first leach field was constructed in the early 1960's and almost immediately it was hypothesized that its operation was likely contributing moisture to the central and southern portions of the dwellings roughly 150 feet below (Horn, 1988). Incidentally these are the same areas that are presently experiencing wetting problems. In addition to the observed seepage, the leach field that was constructed in the overlying siltstone-sandstone layer was rejecting some waste water and raw sewage was exiting on the surface. This problem was "alleviated" by constructing a pipe from the comfort station directly over the edge of the mesa below Cliff Palace. Eventually adverse effects developed in the area of sewage discharge in the form of flora mortality and the practice of sewage piping was discontinued.

A second leach field was constructed in 1989-1990, about 200 yards to the south, both down dip and downslope of the original. This leach field differed in design by being constructed in sand and gravel fill placed on the country rock. This is the leach field that presently services the comfort station. Unfortunately, this field also rejects some effluent, apparently at the lowest elevation of the contact between the fill and the country rock. Even though this new site is located down dip, it could possibly

still supply water to the dwellings by accessing joints that ultimately lead to the rock shelter.

The parking lot, which was expanded in the early 1960's, does not add water to the mesa top but is capable of re-directing and concentrating flow. Furthermore, runoff from part of the parking lot drains to a ditch that may exacerbate seepage to Cliff Palace.

There are two ditches on top of the mesa. The smallest ditch was constructed in 1932 as a "pour-off" control slot that redirects surface runoff that would naturally fall over the mesa onto the exposed part of the cliff dwelling. This small trench was hand dug very close to the mesa edge and apparently does not intersect any vertical joints and probably does not increase infiltration.

In addition to the pour-off control slot, a second runoff ditch with an approximately 400 feet long, about six feet wide, and about three feet deep, was constructed between the parking lot and the edge of the mesa. Because of its location and orientation it is possibly situated either directly over, or very near a vertical joint in the massive sandstone. The location is very significant because this ditch receives concentrated runoff from part of the parking lot and water from bleeding and draining the water supply line. Additionally, the ditch was constructed in such a manner that it does not completely drain, so any water entering it may escape only through evaporation and infiltration. During the site visit, one area in the ditch had very moist soil and fractures within sandstone contained moss, indicating persistent moisture in that area.

Hydrologic Budget

The amount of natural water available for infiltration on the mesa top, is limited by the amount of precipitation over the recharge zone. Based on examination of 7.5 minute, USGS topographic maps, the contributing area is likely less than one square mile, with a more reasonable estimate closer to 0.2 square miles and possibly as little as 0.03 square miles. The uncertainty of these estimates stems from the nature of subsurface flow which, in this case, is influenced by the presence of vertical joints, horizontal joints, and interbedded layers of low permeability. The presence of these joints may allow water to migrate to the site from great distances that are not apparently within the recharge area. Conversely, water that infiltrates in the general vicinity of the site may be transmitted great distances away from the site through fracture flow. Gross meteoric inputs of water to the recharge area are influenced by evaporation and storage both above and below the saturated zone before reaching the rock shelter.

All of these factors can be reasonably estimated to demonstrate the relative magnitude of natural hydrologic input. A range of likely

annual precipitation totals was established by both adding and subtracting one standard deviation (calculated from the precipitation record) from the mean annual precipitation value of 18.32 inches. The high and low estimates for annual precipitation were 22.89 and 13.75 inches, respectively. Using the smallest estimate of recharge area (0.03 square miles) the gross annual input of meteoric water ranges from 7.2 to 11.9 million gallons with an average value of 9.55 million gallons.

All of these values are overestimates relative to the respective precipitation inputs because evaporation constitutes a substantial loss from incident precipitation, especially in this arid environment. Published values of annual average evaporation range from about 55 to 65 inches for this area (Dunne and Leopold, 1978). Compared to the annual precipitation range used for input estimate, evaporation exceeds precipitation anywhere from 240-470 percent.

Direct runoff from the mesa top also removes a considerable amount of water from possible infiltration. Sandstone beds from the Mesa Verde Group are overlain by relatively impermeable beds and therefore receive a relatively small amount of recharge from precipitation (J.H. Irwin, 1966). Previous estimates of infiltration after runoff and evapotranspiration for the southwest range from 5 - 10 percent of annual precipitation (Wilson et.al., 1980). This leaves about 600,000 to 1,200,000 gallons of precipitation annually available for infiltration on the mesa top.

Not all water that infiltrates into the mesa will exit as springs or seeps. Intergranular storage in an unsaturated fine-grained sandstone can account for about one to two gallons per cubic foot of material, not counting additional storage space in fractures (Fetter, 1994). Consequently, the 100-foot thick massive sandstone underlying the recharge area could store between 84 and 167 million gallons, and even a small section above Cliff Palace measuring 400 feet by ten feet (roughly the size of the runoff ditch) could store from 400,000 to 800,000 gallons of water. The majority of this water will either exit the groundwater flow system through seeps and springs or through evaporation at rock surfaces; or possibly enter deep groundwater storage with eventual discharge far below Cliff Palace. This is strongly evidenced in the saturated condition present at the back of the drainage tunnel.

In summary, the natural precipitation of 7-12 million gallons produced annually over the catchment area would initially be reduced by a substantial factor through evapotranspiration and surface runoff. Assuming a loss of from 90 to 95 percent, then from 360,000 to 1,200,000 gallons would be available for infiltration. Of the water that infiltrates, some goes into deep aquifer storage and is essentially removed from the local system. The remainder flows through the saturated zone slowly reemerging through spring flow or evaporation at the rock surface. Massive sandstone is capable of storing quantities of water that exceed

natural input. This storage, however, is finite and when it is completely filled any additional water added to the system will likely cause seepage, possibly in areas where moisture is rare.

Anthropogenic sources of water provide an additional input that appears to be significant in both location and quantity. All additional water reaches the mesa top via the water supply pipe previously described. Periodic bleeding of the pipe is estimated to produce about 500-600 gallons per day or from 90,000 to 110,000 gallons for the 6-month season. At the end of the season, when the pipe is completely drained an additional 3400 gallons is released on the mesa top. The total input of water from pipe maintenance alone is roughly about 93,500 to 113,500 gallons per season. This is not an excessively large quantity compared to natural inputs, only about 8-19 percent; however, it is important to note that this water is released directly to the runoff ditch which appears to overly Cliff Palace and may have hydraulic communication with the vertical joint system. Additionally, the leaks that periodically occur in the line could add a substantial yet indeterminate amount of water to the groundwater flow system.

The leach field associated with the comfort station, while apparently not situated directly over Cliff Palace, provides a substantial input of water to the mesa top. Estimates based on reasonable use place the volume of leachate in the range of 230,000 to 1,300,000 gallons per season. The lowest volume estimate is from 19-38 percent of estimated natural input, but is more concentrated above the Cliff Palace area. As mentioned, the location of the leach field does not appear to be directly over the dwellings, however effluent from the field could possibly access the site through fracture flow, especially if natural inputs are high and available storage is depleted.

The parking lot on the mesa does not produce any water, however paved surfaces can greatly alter the timing and peak of runoff events. Park staff have estimated that about 59,000 square feet of paved area exists on top of the mesa, and it is likely that most of this area contributes water to the runoff ditch. An annual contribution from the parking lot to the ditch could range from about 500,000 to 840,000 gallons, for 13.75 and 22.89 inches precipitation, respectively.

Because it appears that the runoff ditch is coincident with vertical joints in the massive sandstone, it has the potential to contribute water directly to Cliff Palace. Water line operation and parking lot runoff contribute from about 595,000 to 964,000 gallons per year to the ditch. Natural input from precipitation to the ditch based on an area of 400 by 100 feet (no parking lot contribution) could be between 340,000 to 570,000 gallons per year. Comparison of the estimated values indicates that anthropogenic inputs could approach 3-times that of natural. Furthermore,

natural input would be allocated more evenly over time so the magnitude of individual pulses to the ditch would be attenuated.

Once available storage in the unsaturated zone is depleted, the rate of transmission is governed by the bulk hydraulic conductivity of the fractured sandstone. A homogeneous, fine-grained sandstone can transmit water at a rate of 0.4 to 34 inches per day (Fetter, 1995). For a thickness of 100 feet this translates into a seepage time from 35 days to as much as 8.2 years. Actual seepage rates through the rock unit are harder to quantify due to inhomogeneities in the form of changes in lithology and variable degrees of cementation. The presence of vertical joints would likely serve to increase the rate of water transmission, so a seepage rate closer to a few tens of days would serve as a most reasonable estimate.

The final input of anthropogenic water for the 1995 season occurred to the mesa top in October when the water supply line was drained into the ditch. Groundwater seepage in the shelter began roughly two weeks after the final input of water to the surface. ~~Considering the range of probable seepage rates, it is not~~ unreasonable to presume that the cumulative effects of above average precipitation from the preceding years coupled with the anthropogenic water overwhelmed the natural storage.

In summary, the estimated anthropogenic inputs from the leach field and water line operation (not counting leaks) contribute from 323,500 to 1,400,000 gallons annually, or from 27 to 230 percent of estimated natural precipitation over the entire recharge area. More striking is the fact that anthropogenic input to the ditch (parking lot runoff and water line operation), which likely has a direct vertical route to Cliff Palace, may be as much as 3-times natural input to the same area.

Water Chemistry

{will add a summary of available water chemistry data from the event}

Conclusions

The water that is presently entering Cliff Palace is primarily of anthropogenic origin. Precipitation from recent wet years likely filled most of the available storage in the massive sandstone. The additional pulse of anthropogenic water, concentrated in critical areas was enough to produce substantial seepage. It appears that the most detrimental activities are those that place water in the runoff ditch directly over the shelter. Specifically; bleeding and draining of the water line, allowing runoff from the parking lot to enter the ditch, and possibly leaks in the water line. This conclusion is supported through two main lines of evidence: 1) the relative volumes of natural and anthropogenic water to the mesa top

and specifically the ditch; and 2) the late-season occurrence of the water, which incidently occurred roughly two weeks after the final draining of the water line, and after two seasons of bleeding water into the ditch. The leach field may also be a contributor of water to Cliff Palace, although when the length of leach field operation (5-6 years) is considered, it appears that it does not produce constant seeping into the shelter.

In terms of preserving the dwellings, no water is good water. More explicitly, any anthropogenic water released on top of the mesa runs the risk of adversely affecting dwellings on any of the surrounding cliff faces, either through direct saturation or weakening of the surrounding rock structure. This is not to say that all water impacts the structures because much volume is lost from the system through springflow, evaporation on the rock surfaces, deep aquifer storage, and in the case of Cliff Palace, discharge to the tunnel. Nevertheless, the risk of impacting the dwelling may outweigh the benefits of water use. Consequently, any decisions to release water on the mesa top should be preceded by a comprehensive hydrogeological analysis.

Possible Solutions

The most direct way to reduce impacts of anthropogenic water is complete elimination of water use on the mesa top. This would possibly alleviate serious wetting of the ruins and therefore is advisable. The main drawbacks to this option are the reduction in visitor comfort and the increased cost of providing self contained toilets. A less expensive and possibly more effective measure may be to alter activities that supply water to the ditch. Furthermore, the ditch could possibly be redesigned to greatly diminish vertical infiltration. This option assumes that the 230,000 to 1,300,000 gallons leaving the comfort station does not access Cliff Palace, a conclusion which has not been made at this time. Furthermore, continued operation of the comfort station could supply an undetermined amount of water to the subsurface through leaks in the line. It may be possible to install a meter on the line to estimate the volume of these leaks.

A more resource-intensive solution may be to extend the drain tunnel. This option could likely be completed and would probably be beneficial in alleviating moisture problems, both natural and anthropogenic. The main drawbacks to this option are the cost in dollars and the possibility of de-stabilizing the Cliff Palace area. Additionally this would do nothing to protect other dwellings on the cliff face. A modified version of this would be to construct a "weep" gallery. If properly located, a series of holes in the bedrock could possibly intercept groundwater flowing toward the rock shelter. It is not clear if such a gallery is at all possible given the natural setting and equipment limitations. A thorough engineering feasibility study of either of these options

if present
with water
is above
(directly
over
shelter)
how would
tunnel
intercept the
water
flow

should be conducted prior to any serious consideration.

The lowest level solution would be to monitor the site(s) and implement ad-hoc measures when detrimental seepage occurs. This is the default option and the one that is presently being used. The advantages are that it is relatively cheap and easy. The disadvantages are that it is less than 100 percent effective and requires substantial staff awareness and labor. Additional to this water could be pumped into a tanker truck and dumped somewhere benign.

Additional Investigations

One of the elements missing from this analysis is quantitative spatial data. This would allow a more accurate estimation of the proximity of anthropogenic sources of water to Cliff Palace. A detailed topographic survey could be supplemented through examination of aerial photographs if available. Furthermore ~~spatial data could possibly link the location of the ditch to~~ vertical joints. The benefit of performing this analysis would be to establish a more quantitative hierarchy of likelihoods of impact from different sources. This may allow park staff to eliminate the most detrimental activities while maintaining some of the least detrimental at a reduced cost to total elimination. The downside is that there could still be uncertainty in flow paths making unequivocal determinations impossible.

An additional line of investigation would be to collect and compare water chemistry samples with the intent of finding a significant difference in the chemical signatures of natural and anthropogenic water. It may be possible to distinguish between supply water, leach field effluent and natural groundwater by comparing the chemical parameters of chloride, chlorine, bacteria, nitrate/nitrite, phosphate, major ions and isotopes. The drawback to this approach is that chemical analysis in any quantity can be expensive and that natural chemical variability in the system may be enough to mask differences between anthropogenic and natural discharge.

The Park may want to consider submitting a Project Statement to WRD for initiation of a detailed study.

Acknowledgments

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