The relationship between the water table and the surface flow of a losing stream, lower Medano Creek, Great Sand Dunes National Monument, Colorado

G. L. Hadlock · T. E. Lachmar · J. P. McCalpin

Abstract Proposed groundwater withdrawals in the San Luis Valley of Colorado may lower the water table in Great Sand Dunes National Monument. In response, the National Park Service initiated a study that has produced a generalized conceptual model of the hydrologic system in order to assess whether a lowering of the water table might decrease the surface flow of lower Medano Creek. Based upon information obtained during the drilling of several boreholes, there appear to be five important hydrostratigraphic units underlying lower Medano Creek within the upper 30 m of the ground surface: 1. a perched aquifer overlying an aquitard located between about 5 and 6 m below the ground surface; 2. the aquitard itself; 3. an unconfined aquifer located between the upper and lower aquitards; 4. an aquitard located between about 27 and 29 m below the ground surface; and 5. a confined underlying the lower aquitard. Because the areal extent of the aquitards cannot be determined from the borehole data, a detailed conceptual model of the hydrogeologic system underlying lower Medano Creek cannot be developed. However, a generalized conceptual model can be envisioned that consists of a complex system of interlayered aquifers and leaky aquitards, with each aquifer having a unique hydraulic head. Water levels in the perched aquifer rise rapidly to their annual maximum levels in response to the arrival of the flow terminus of Medano Creek during the spring runoff event, and the location of the flow terminus is directly dependent upon the discharge of the creek. Water levels in the deeper, non-perched aquifers do not appear to fluctuate significantly in response to the arrival of the flow terminus, demonstrating that it is unlikely that the proposed groundwater withdrawals will decrease the surface flow of lower Medano Creek.

Key words Hydrogeology · Surface water · Groundwater · Streamflow

Received: 27 December 1995 · Accepted: 20 February 1996

G. L. Hadlock
Radian Corporation, 4021 South 700 East, Suite 600, Salt Lake City, UT 84107, USA

T. E. Lachmar (✉)
Department of Geology, Utah State University, Logan, UT 84322-4505, USA

J. P. McCalpin
GEO-HAZ Consulting, Inc., P.O. Box 1377, Estes Park, CO 80517, USA

Introduction

Great Sand Dunes National Monument is located on the eastern margin of the San Luis Valley in south-central Colorado (Fig. 1). Streams from the adjacent Sangre de Cristo Mountains flow into the monument from the east. The largest of these streams, Sand Creek, enters the monument at its northern boundary. Medano Creek, a somewhat smaller stream, enters the monument near its northeastern corner and then trends south and southwest, forming the eastern margin of the active dune field. Both streams are losing streams throughout their entire reaches after they cross the monument boundary, and sink into the subsurface sediments before reaching any other surface water body. The locations where the surface flow terminates for these two streams varies seasonally, advancing downstream in the spring and retreating upstream in the late summer and fall.

Impending groundwater withdrawals in the adjacent Baca Grande property north of Great Sand Dunes National Monument have been projected to lower the water table within the monument by up to 46 m. Such a lowering of the water table may adversely impact or eliminate the pulsating flow that occurs on Medano and Sand Creeks. Pulsating flow is rare (Bean 1977; Schumm and others 1982), and the occurrence at the monument is a unique visitor attraction. The Park Service is concerned with the effect that a lowered water table might have on the pul-

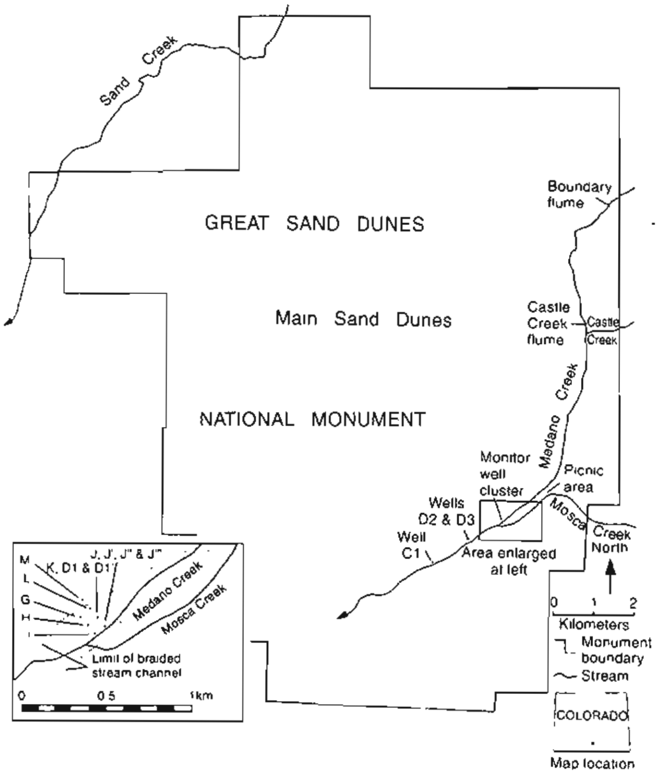

Fig. 1
Location map of the Great Sand Dunes National Monument showing flume and monitor well locations

sating flow along Medano Creek in the vicinity of the picnic area (Fig. 1), because this area is accessible to most visitors. The picnic area is inundated by the creek only when the discharge is relatively high during late spring and early summer, generally from April through August. In addition, loss of streamflow due to water-table lowering could allow eastward encroachment of the active dunefield into developed parts of the monument.

The objectives of this study were to: 1. measure the discharge of Medano Creek at several locations to quantify the spatial and temporal variations in stream losses; 2. measure the depths to groundwater in monitor wells in the Medano Creek floodplain to quantify the spatial and temporal variations in groundwater levels; 3. establish the relationship between the discharge and the location of the terminus of flow of Medano Creek with the water levels in the shallow groundwater flow system; 4. establish the relationship between the shallow groundwater flow system and the regional water table; and 5. develop a conceptual model of the surface water/groundwater system along lower Medano Creek.

Stream losses

For the purpose of evaluating the stream losses, Medano Creek can be divided into two sections: 1. the gravel-bed section from the headwaters to the confluence with Castle Creek, where the stream bed is relatively narrow and has steep, vegetated banks; and 2. the sand-bed section from the confluence with Castle Creek to the terminus of flow, where the stream bed is relatively wide and the channel is braided.

Two Parshall flumes were constructed and installed on Medano Creek in order to measure the stream losses in the gravel-bed section of the creek. The flumes' dimensions were dictated by the dimensions of calibrated flumes tested by the U.S. Bureau of Reclamation (1984). The upstream (Boundary) flume was located approximately 100 m downstream from the point where the creek enters the monument to provide a measurement of streamflow entering the monument (Fig. 1). The downstream (Castle Creek) flume was located about 100 m upstream of the confluence with Castle Creek, at the last channel section narrow enough to accomodate a flume. The Boundary flume was installed on 28 June 1991 and allowed a nearly continuous record of discharge measurements to be obtained for the periods from 28 June 1991 to 6 November 1992 (Fig. 2), and from 7 March to 25 May 1993. The Castle Creek flume began recording on 28 June 1991 also, but it was undermined by high spring runoff in April 1992, and was dismantled in October of 1992. In addition, data were not recorded for the periods from 9 July to 19 August 1991 and from 28 August to 15 September 1991.

Due to both daily and diurnal fluctuations, the amount of streamflow that was lost between the Boundary and Castle Creek flumes ranged from about 0.065 to 0.217 cubic meters per second (m^3/s) during the peak discharge period in the early summer (Fig. 3). As this section of the creek is approximately 4.3 km long, the stream loss rate varied from about 0.015–0.050 m^3/s per km.

Standard velocity/cross-sectional area measurements were performed in the sand-bed section of Medano Creek. Estimating stream losses in the sand-bed section of Medano Creek presents a major logistical problem, because dis-

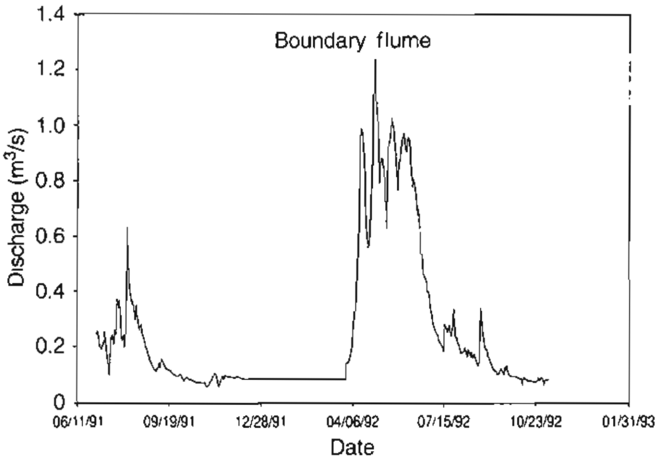

Fig. 2
Discharge of Medano Creek at the Boundary flume from 1 July 1991 to 6 November 1992

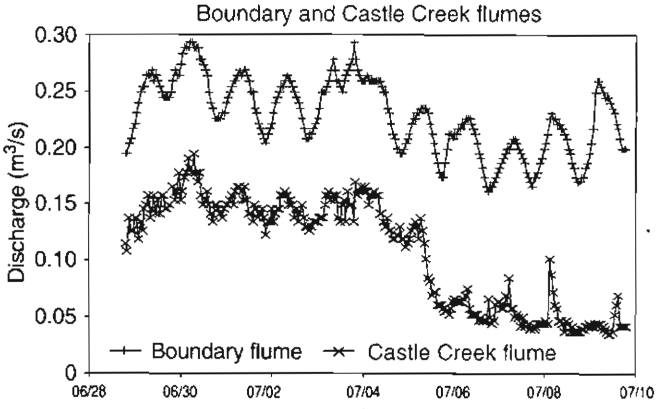

Fig. 3
Discharge of Medano Creek at the Boundary and Castle Creek flumes from 28 June to 9 July 1991

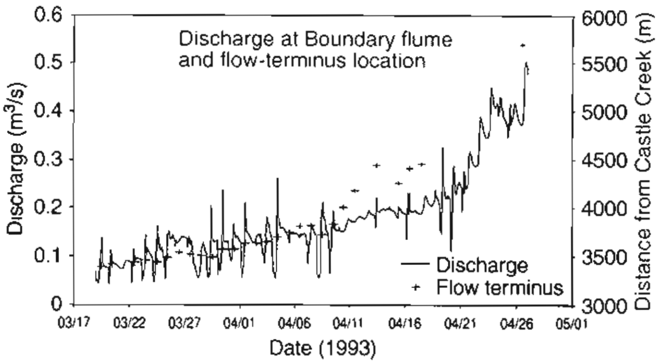

Fig. 4
Discharge at the Boundary flume and flow-terminus location on Medano Creek from 19 March to 26 April 1993

charge measurements are difficult to make simultaneously at two different locations in the stream bed. Because the discharge fluctuates diurnally, measurements taken at different times cannot necessarily be used to estimate stream losses. This problem was overcome by making an upstream measurement, then a downstream measurement and then another upstream measurement, and then averaging the two upstream measurements to obtain an approximate upstream discharge at the time the downstream measurement was made. Using this technique, an average stream loss of 0.105 m^3/s was estimated using several sets of upstream and downstream discharge measurements during the relatively high flow period between 20 and 24 June 1991. As the distance between the upstream and downstream measurement points was approximately 1.6 km, the stream loss rate for the sand-bed section of the creek is about 0.066 m^3/s per km, or roughly 1.5–4.5 times greater than that measured for the gravel-bed section.

Terminus-of-flow location

The location of the terminus of flow of Medano Creek was measured by Park Service personnel between about noon and 1:00 P.M. each day from 19 March to 17 April 1993, and again on 26 April 1993, by pacing downstream from the same point. A graph of the location of the flow terminus and the discharge of Medano Creek at the Boundary flume with time (Fig. 4) shows that the two plots are quite similar in shape. The terminus-of-flow location advanced slowly downstream from 19 March to 9 April, and then advanced rapidly from 10 to 13 April. The terminus-of-flow location then remained at nearly the same location from 13 through 17 April, before making a large advance sometime between 17 and 26 April. Similarly, the discharge of Medano Creek recorded at the Boundary flume increased slowly from 19 March to 22 April, and then increased rapidly from 22 through 26 April.

Hydrogeologic data

Six shallow groundwater monitor wells (wells G, H, I, J, K and L) were installed by Park Service personnel in the Medano Creek floodplain in December 1990 near the confluence with Mosca Creek, which is located immediately downstream of the picnic area (Fig. 1). A seventh well (well M), located approximately 75 m farther toward the main dune mass from well L, was added to the monitor-well cluster on 25 August 1991. Unfortunately, neither geologic logs nor completion data were recorded by the Park Service personnel involved in the installation of these seven monitor wells.

Five additional monitor wells and three other boreholes were drilled in the Medano Creek floodplain for this investigation. Two boreholes, J′ and J″, and monitor well C1 were drilled using a Gittings trailer-mounted solid-stem auger rig on 7 and 8 April 1992. Boreholes J′ and J″ were drilled adjacent to well J, and monitor well C1 was drilled in the center of the Medano Creek floodplain about 3 km downstream of well J (Fig. 1). The same stratigraphy was encountered in each well: about 2–3.5 m of well-sorted medium sand, underlain by 1.5–2.5 m of gravelly sand, underlain by a hard, fine-grained layer at least 1 m thick. The Gittings solid-stem auger rig was unable to penetrate the fine-grained layer; thus, no sample of this layer was obtained using the Gittings rig.

Because of the inability of the Gittings solid-stem auger rig to penetrate the hard, fine-grained layer, four additional monitor wells, J‴, D1, D1′ and D3, and one other borehole, D2, were drilled using a track-mounted hollow-stem auger rig on 17, 18, 19 and 24 August 1993. Monitor well J‴ is located next to monitor well J and boreholes J′ and J″, monitor wells D1 and D1′ are located next to monitor well K, and borehole D2 and monitor well D3 were located roughly midway between monitor well K and monitor well C1 (Fig. 1).

Monitor well L

Monitor well L was monitored from 7 December 1990 to 6 November 1992 (Fig. 5). Well L was monitored nearly continuously during the period from September 1991 to November 1992 using a pressure transducer connected to a data logger. The hydrograph for monitor well L during this period can be divided into four segments. The first segment is a period of slow water-level decline from September 1991 to April 1992. The water level in well L fell slowly and steadily (about 1.4 m in 6 months) throughout the late summer, fall, winter and early spring.

The second segment is a period of rapid water-level rise from April to June 1992. The terminus of flow of Medano Creek was observed to arrive at the monitor-well cluster on 8 April; thus, the rapid rise in monitor well L roughly coincides with the arrival of the flow terminus. The discharge of Medano Creek recorded at the Boundary flume on 8 April was 0.33 m^3/s.

The third segment is a period of constant water level from June to September 1992, during which time the Boundary flume records indicate that the discharge declined from about 1.0 to 0.2 m^3/s. The water level in monitor well L stood at about 1.2 m below the top of the well casing throughout this period, with two minor fluctuations. One of the minor fluctuations is a period of water-level decline during the first half of July. The discharge at the Boundary flume declined slightly during this period, from about 0.3 to 0.2 m^3/s, so the water-level decline probably indicates that the flow terminus had retreated to just upstream of the monitor-well cluster during this period. The other minor fluctuation is a period of water-level rise during the second half of July. This rise coincided with a sudden increase in discharge of about 0.1 m^3/s at the Boundary flume due to the return of water that previously had been diverted from the creek at Medano Pass for irrigation. Had this increase in discharge not occurred, the water level probably would have continued the downward trend that began in early July. Instead, the additional surface flow in the creek must have readvanced the flow terminus to downstream of the monitor wells.

The fourth segment is a period of rapid and then slow water-level decline from September to November 1992. During the first half of September, the water level declined 0.6 m. This rapid decline must represent the final seasonal retreat of the flow terminus to upstream of the monitor wells. During the remainder of this period, the water level declined slowly from about 1.9 to 2.3 m below the top of the casing. This slow decline is virtually identical to that observed during the first segment from September 1991 to April 1992.

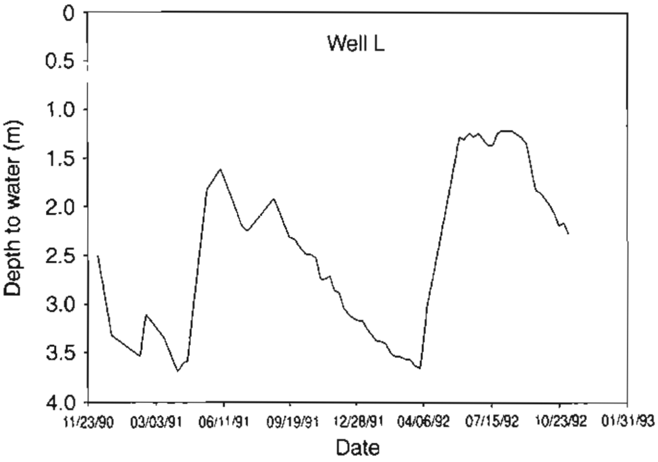

Fig. 5
Depth to water in monitor well L from 7 December 1990 to 6 November 1992

Monitor well J

The water level in monitor well J was recorded throughout the spring runoff period from 18 March to 10 May 1993 using a pressure transducer connected to a data logger (Fig. 6). The data show that a constant water level at about 1.4 m below the top of the well casing existed until 22 April. From 22 through 23 April, the water level rose slowly, and then late on 23 April the rate of rise increased greatly. The water level rose about 1.1 m in the next 4.5 days, coming to a new stable position at 0.3 m below the top of the casing on the morning of 28 April. This rise in the water level is attributed to the arrival of the flow terminus. This supposition is supported by the similar reaction of monitor well L to the arrival of the flow terminus in the spring of 1992. However, no observations of the location of the flow terminus were made between 17 and 26 April 1993 (Fig. 4), so this supposition cannot be strictly verified. By linear interpolation, the date of the arrival of the flow terminus at monitor well J can be predicted to be about mid-day on 22 April. This date coincides with the beginning of the period of slow water-level rise. The discharge of Medano Creek recorded at the Boundary flume on 22 April 1993 increased from 0.32 to 0.36 m^3/s, which is comparable to the discharge

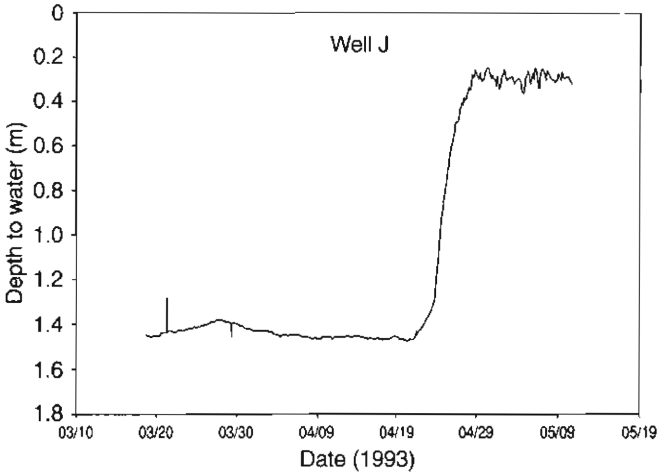

Fig. 6
Depth to water in monitor well J from 18 March to 10 May 1993

of 0.33 m^3/s measured on 8 April 1992, when the flow terminus was observed to arrive at the monitor-well cluster during the previous year.

Monitor well C1

Monitor well C1 was drilled to a total depth of 4.54 m, and was screened between 4.24 and 4.54 m below the ground surface. The water level in monitor well C1 was recorded from 10 to 28 April 1992 using a pressure transducer connected to a data logger (Fig. 7). The water level remained at the very bottom of the well from 11 to 18 April. Then on 18 April, the water level began to rise rapidly, gaining all 4.54 m in about 30 h. This extremely rapid rise in water level implies that the water infiltrating from the stream bed is being impeded in its downward movement by the hard, fine-grained layer at the bottom of well C1. Presuming that the rapid rise in water level in monitor well C1 on 18 April coincided with the arrival of the terminus of flow of Medano Creek, the flow terminus advanced the 3 km from monitor well L to monitor well C1 in 10 days. The discharge of Medano Creek recorded at the Boundary flume increased from 0.33 m^3/s on 8 April to 0.99 m^3/s on 15 April, and then decreased slightly to 0.93 m^3/s by 18 April.

Monitor well J‴

Monitor well J‴ was drilled to a total depth of 7.5 m, and was screened between 5.9 and 7.4 m below the ground surface. The screen was placed below a 0.6-m-thick hard, fine-grained layer located between 5.2 and 5.8 m. A sample of this layer was obtained during the drilling by inserting a split-spoon sampler inside the hollow-stem auger, and the sample showed this layer to be composed of silty, fine-to-medium sand with some clay and gravel. The depth to water in J‴ was measured at 6.94 m below the ground surface; thus, about 1.1 m of unsaturated sand lies underneath the fine-grained layer, demonstrating that this material acts as an aquitard which separates an upper perched aquifer from a lower unconfined aquifer.

Monitor well D1

Monitor well D1 was drilled to a total depth of 30 m, and it was completed with a 6-m-long screen located between 23.7 and 29.7 m below the ground surface. The screen was placed through a 1.2-m-thick hard, fine-grained layer located between 27.4 and 28.6 m. No sample of the fine-grained layer in monitor well D1 was obtained, but it is probably similar in composition to the hard, fine-grained layer encountered in monitor well J‴.

Upon completion, water could be heard cascading down the inside of the casing in monitor well D1, indicating that water was flowing from an upper aquifer into a lower aquifer through the well screen. This observation demonstrates that the fine-grained layer encountered in monitor well D1 also acts as an aquitard, in this case separating an upper unconfined aquifer, which may correlate with the lower unconfined aquifer noted in monitor well J‴, from a lower aquifer.

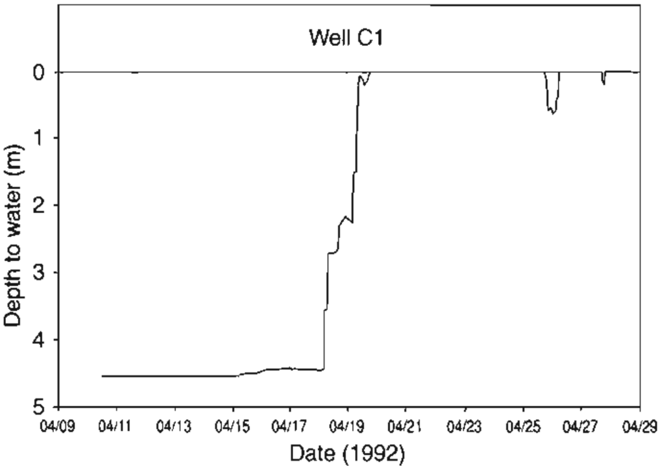

Fig. 7
Depth to water in monitor well C1 from 10 to 28 April 1992

The water level in monitor well D1 was measured periodically by Park Service personnel from 27 September 1993 to 7 November 1995 (Fig. 8). The water level in this monitor well remained relatively constant during this period, fluctuating only 0.94 m. Furthermore, the water level in well D1 reached its lowest level during the spring of 1994, indicating that the two aquifers well D1 is completed into probably are not affected by the arrival of the flow terminus of Medano Creek during the annual spring runoff event.

Monitor well D1′

Monitor well D1′ was drilled within a few meters of monitor well D1 in order to try and free up the auger flights that became stuck when D1 was drilled. Monitor well D1′ was drilled to a total depth of 30 m, and encountered the same stratigraphic units as monitor well D1. Monitor well D1′ was completed with a 1.5-m-long screen located between 28.7 and 30.2 m below the ground

Fig. 8
Depth to water in monitor well D1 from 27 September 1993 to 11 November 1995

surface. The depth to water in monitor well D1′ was measured at approximately 28 m below the ground surface, which is above the base of the aquitard and indicates that the lower aquifer is confined. Unfortunately, the PVC casing in monitor well D1′ was destroyed shortly after it was installed, when some of the auger flights that became stuck when well D1 was drilled were removed. Thus, the water level in the lower confined aquifer could not be monitored.

Borehole D2

Borehole D2 was drilled to a total depth of 15 m. No PVC casing was installed in borehole D2 because no hydrologically significant stratigraphic units were encountered, as it did not intercept any fine-grained layers.

Monitor well D3

Monitor well D3 was drilled to a total depth of 30 m, and was completed with a 3-m-long screen located at the bottom. Unfortunately, no geologic log was recorded for this well by the Park Service personnel who were present at the time it was drilled. However, the water level in well D3 was measured periodically by Park Service personnel from 18 October 1993 to 7 November 1995 (Fig. 9). As with monitor well D1, the water level in well D3 remained relatively constant during this period, fluctuating only 0.79 m, and reached its lowest level during the spring of 1994. Thus, it appears that the deep aquifer(s) well D3 is completed into, which may correlate with one or both of the deep, non-perched aquifers monitor well D1 is completed into, probably is not affected by the arrival of the flow terminus of Medano Creek during the annual spring runoff event either.

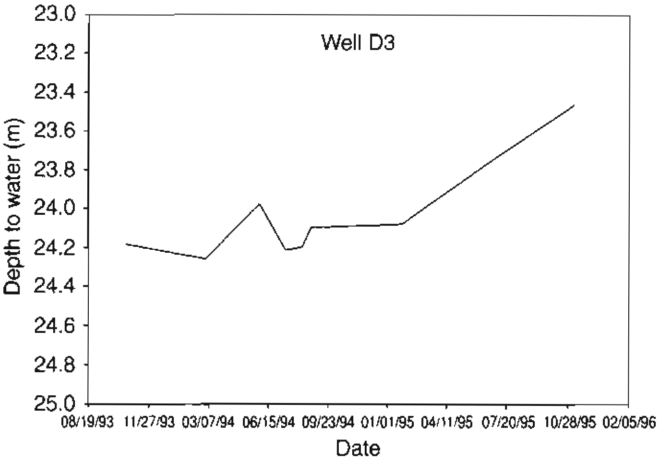

Fig. 9
Depth to water in monitor well D3 from 18 October 1993 to 7 November 1995

Discussion

Based upon the information obtained during the drilling of the five monitor wells and three boreholes, there appear to be five important hydrostratigraphic units underlying the lower Medano Creek stream channel within the upper 30 m of the ground surface. The first is a perched aquifer overlying an aquitard located between about 5 and 6 m in monitor well J‴. The second is this aquitard itself. The third is the unconfined aquifer located between the upper and lower aquitards. The fourth is the aquitard located between about 27 and 29 m in monitor wells D1 and D1′, and the fifth is the confined aquifer underlying the lower aquitard.

The two aquitards obviously must play a major role in the hydrologic interaction between Medano Creek and the three aquifers, but unfortunately there is no reliable information on their areal extent. Although the shallow aquitard is present at monitor well C1, it seems fairly certain that it is not continuous, as nothing remotely similar to it was encountered in borehole D2. In addition, there is no reliable information available on the areal extent of the lower aquitard found in monitor wells D1 and D1′, as monitor well D3 was the only other well drilled to a depth of 27 m and no geologic log was recorded for this well.

Because of the lack of information on the areal extent of the aquitards, a detailed conceptual model of the entire hydrogeologic system cannot be developed. A generalized conceptual model of lower Medano Creek based on the monitor well and borehole records can be envisioned as a complex hydrogeologic system consisting of several thin low-hydraulic-conductivity layers with limited areal extent (Fig. 10). This is similar to the conceptual model developed by Hearne and Dewey (1988). Their conceptual model consisted of a complex system of interlayered aquifers and leaky confining layers, with each aquifer having a unique hydraulic head.

The relationship between the location of the flow terminus and the shallow groundwater system underlying lower Medano Creek appears to be fairly simple. Water levels in the monitor wells rise rapidly (within 30 h at monitor well C1 and 4.5 days at monitor well J) to their annual maximum levels in response to the arrival of the flow

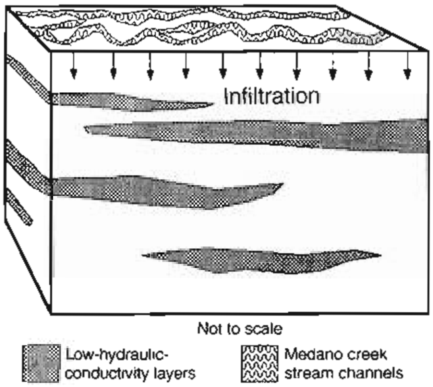

Fig. 10
Generalized conceptual model of lower Medano Creek (Hadlock 1995)

terminus. Thus, the water table in the perched aquifer underlying lower Medano Creek is controlled by the terminus-of-flow location.

In addition, the location of the flow terminus seems to depend on the discharge of Medano Creek, as it appears that a discharge of approximately 0.35 m^3/s at the monument boundary is necessary during the annual spring runoff event for the terminus-of-flow location to advance to the monitor-well cluster. If the amount of streamflow lost along the gravel-bed section of Medano Creek between the Boundary and Castle Creek flumes is assumed to be on the order of 0.1 m^3/s (see Fig. 3), then the stream loss rate for the sand-bed section of the creek between the Castle Creek flume and the monitor-well cluster, which are approximately 5 km apart, is about 0.05 m^3/s per km, which compares favorably with the value of 0.066 m^3/s per km measured in June 1991.

Finally, water levels measured by Park Service personnel in monitor wells D1 and D3 from the fall of 1993 to the fall of 1995 displayed fluctuations of less than 1 m and reached their lowest levels in the spring of 1994, demonstrating that the deeper, non-perched aquifers are probably not affected by the arrival of the flow terminus of Medano Creek during the annual spring runoff event. Thus, it seems unlikely that the proposed groundwater withdrawals will decrease the surface flow of lower Medano Creek.

Acknowledgements Financial support for this project was made through the National Park Service, Rocky Mountain region cooperative agreement number CA 1268-1-9006. In addition, several Park Service personnel provided invaluable assistance during the course of this investigation, especially Superintendent Bill Wellman and Ranger Fred Bunch.

References

Bean DW (1977) Pulsating flow in alluvial channels. MS thesis. Colorado State University, Fort Collins, Colorado. 124 pp

Hadlock GL (1995) Groundwater and surface water interactions along lower Medano Creek, Great Sand Dunes National Monument, Colorado. MS thesis. Utah State University, Logan, Utah. 81 pp

Hearne GA and Dewey JD (1988) Hydrologic analysis of the Rio Grande Basin north of Embudo, New Mexico, Colorado and New Mexico. US Geological Survey Water-Resources Investigations Report 86-4113. 244 pp

Schumm SA, Bean DW, and Harvey MD (1982) Bed-form-dependent pulsating flow in Medano Creek, southern Colorado: Earth Surf. Processes Landforms 7:17–28

US Bureau of Reclamation (1984) Water Measurement Manual. Denver, Colorado. p 327