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MOAB PROJECT

Migration Potential of the Colorado River Channel Adjacent to the Moab Project Site

Letter Report

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Prepared by
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Introduction

The February 2003 update of this paper includes new information obtained over the summer of 2002. A drilling program was completed during the summer that further defined the site ground water regime. Results from this investigation provided geologic information relevant to understanding potential river migration.

Newly obtained information includes:

- Knowledge of subsurface stratigraphy.
- A radiocarbon date of a wood fragment obtained from within alluvial gravels at a depth of 89 feet beneath the upper contact.
- Historic topographic/cadastral survey maps of the Moab Valley showing the river course from the years 1884, 1912, 1924, and 1959.
- Review of a recent paper pertaining to sediment transport and discharge characteristics of a reach of the Colorado River that includes the Moab Project site region.

Additionally, an independent review of the original report is included in Attachment 1. A review by the U.S. Army Corps of Engineers of this updated report is included in Attachment 2.

This paper assesses the migration potential of the Colorado River channel adjacent to the tailings pile at the Moab Project Site and presents discussions of processes that can contribute to river migration. Although a conclusive prediction of future river movement is not possible, evidence suggests that the river is and will continue migrating to the south and east away from the existing tailings pile.

The evidence that suggests southward and eastward river migration includes:

- Morphology and stability of the current river channel.
- Historical evidence of river migration.
- Morphology of basin-fill sediments in the Moab Valley.
- Rate and character of salt dissolution in the Moab Valley area.
- Results of limited field investigations.

River migration potential is discussed by evaluating information from different time scales: recent time as suggested by current river morphology, historical time as determined from aerial photographs, and long-term (geologic) time. Recent river channel migration potential is discussed through a review of the current river morphology; historical migrations are illustrated on aerial photographs from the 1940s to the present; the geomorphology of salt dissolution coupled with Quaternary basin-fill sediments provides geologic evidence for long-term migration potential; and results from a limited field reconnaissance provide insight into river migration over the last 12,000 to 30,000 years.

River Channel Migration Potential

Recent Time Scale—Suggested From Recent River Morphology

Alluvial rivers flow through sediments that have been eroded and deposited by the river (Schumm et al. 2000). The Colorado River adjacent to the Moab Project Site flows through sediments deposited by the Colorado River; thus, this reach of the river is assumed to be an alluvial river channel. The potential for the current river channel to migrate can be assessed by considering the present morphology of the channel (Chorley et al. 1984). Channel stability varies depending on discharge gradient, bank sediment strength, bank height, and presence of bank vegetation (Schumm et al. 1988). River channel patterns are defined as straight, sinuous, meandering, and braided. A river alignment will change naturally with time due to flow dynamics and sediment position because fluid-imposed shear stresses exceed strength of sediments (Chorley et al. 1984). However, channels do not fall easily into one category, but change gradually from one to another (Leopold and Wolman 1957). Channels that have high relative stability have low width to depth ratios, low gradients, and shifting alternate bars; they transport fine-grained sediments as a suspended load and are straight to meandering. Conversely, channels with a low relative stability generally have high width to depth ratios, high gradients, and braided channel; they shift channels by avulsion and transport a bedload of coarse gravel and cobbles. Figure 1 shows the Colorado River near the Moab Project Site. This river reach is defined where the river flows through the bedrock entrance to the Moab Valley to its bedrock exit at the Portal. As shown on Figure 1, this reach of the river has vegetated islands, mid-channel bars, and point bars. Relative channel stability descriptors have been developed related to channel patterns shown in Figure 2. Patterns 2 and 4 in Figure 2 best represent the Colorado River near the Moab Project Site. If it were not for the bedrock controls at the river's entrance and exit from the Moab Valley, pattern 2 would most accurately represent the channel pattern. However, because the river must turn to exit the valley, pattern 4 also represents the current condition.

Another method to assess relative channel stability is by comparing the existing channel slope and discharge to those of other stable channels (Leopold and Wolman 1957). Figure 3 relates channel slope to bankfull discharge and shows groupings of braided, straight, and meandering rivers. Meandering channels are in quasi-equilibrium, indicating relative stability.

Leopold and Wolman (1957) qualitatively discuss the formation of islands and mid channel bars. The process they describe is interpreted to be the one that has lead to the formation of bars and islands adjacent to the Moab tailings pile. Their process was developed from field observations confirmed in laboratory flume studies. A short, submerged, central bar is deposited in an undivided channel consisting of coarse particles as the transport capacity of the river is locally exceeded. Subsequent deposition of coarse particles continues until eventually a fine-grained fraction is trapped within the coarser material and the bar accretes upward. Fines carried over the growing bar are deposited on the downstream end of the bar due to a decrease in flow velocity and transport capacity. The bar now grows in a downstream direction. Downstream growth is stabilized by vegetation, and an island forms. Islands behave as channel banks as flanking channels deepen and the island sides become erosion resistant.

Atlas Minerals Corporation and its engineering consultant, Canonie Environmental, commissioned Mussetter Engineering, Inc. in 1994 to investigate migration characteristics of the Colorado River near the tailings pile. A hydraulic analysis of the river was performed with a

computer model using the U.S. Army Corps of Engineers river analysis system, HEC–2. River geometry required for this model includes the channel slope and cross-sectional area. Cross-sections surveyed for this analysis by Mussetter Engineering (Mussetter and Harvey 1994, Appendix A) indicate an average bed slope of 0.025 percent, an average width to depth ratio of 54, and a bankfull discharge estimate of 40,000 cubic feet per second (cfs). Stable channels are narrow and deep possessing a width to depth ratio less than 10. Depending on the valley slope, the channel can be straight or have a high sinuosity (Chorley et al. 1984). As the width to depth ratio increases to values greater than 40, there is a tendency for meandering or multiple thalwegs to form, as shown by pattern 2 or 4 on Figure 2 (Chorley et al. 1984).

If the Colorado River flowing through the Moab Valley is represented by channel pattern 2 or 4 on Figure 2, showing alternate bars shifting slowly downstream as the thalweg, or lowest point of the channel cross-section, shifts position. This results in a moderate relative stability. With a bankfull flow rate of 40,000 cfs and a channel slope of 0.025 percent, the relationships presented by Leopold and Wolman (1957) indicate a stable meandering channel pattern.

The current morphology of the river and accepted channel classifications indicate that the Colorado River adjacent to the Moab Project Site is moderately stable to stable, that is, there is a tendency for thalweg migration within the river banks, but the river banks themselves are not prone to migration.

Additional Results Obtained From the Mussetter Engineering Investigation

- The Colorado River within the project reach, the Moab Valley, has limited degrees of freedom for adjustment. The river's length and its ability to develop a sinuous pattern is constrained by bedrock inlet and outlet conditions.

- The tailings pile and former millsite are sited on an alluvial fan developed from Moab Wash and Courthouse Wash. Both washes have delivered significant quantities of sediment to the area in the past, and deposition will continue unless significant changes occur in the upstream watersheds.

- Sediment input from Courthouse Wash and Moab Wash tends to push the river channel south and prevents lateral migration to the north.

- Very coarse sediment material is currently buried beneath the site (confirmed by Dames and Moore [1982], boring ATP–1, indicating sands, gravels, and cobbles more than 406 feet deep) existing in the river along the right (west) bank adjacent to the tailings pile. Interaction between river flows and this coarse deposit has led to the development of a naturally armored toe that maintains the current course of the river.

- Comments on erosion of the right bank adjacent to the tailings pile:

  — The combined effect of the Portal causing backwater buildup during bankfull flow and at flood stage, coupled with overbank flows into the Scott Matheson Wetlands (Moab Marsh) along the river's left (east) side, significantly reduce erosional stresses on the right side of the river.

  — With respect to both magnitude and duration of flows, over 95 percent of the total energy expended, or work, on the channel banks occurs at flows less than the bankfull discharge at 40,000 cfs.

— Results of the HEC–2 model performed for the river reach adjacent to the site indicate that average channel velocities along the right bank are well below erosional velocities of less than 1 foot per second. A left bank levee across from the tailings pile failed in 1984, which resulted in a reduction of right bank erosion. When the levee was in place, flows up to 70,000 cfs were contained within the banks, causing higher right bank erosional stresses and velocities. However, during the time the levee was in place, the right bank continued to aggrade.

The Mussetter report concludes that because frequent flows of less than the bankfull discharge in the river are responsible for virtually all work done on the right channel bank, and because higher flows cause very little stress on the right bank geomorphological features, that is, the alluvial fans of Moab and Courthouse Washes, there is little reason to believe that the river will migrate laterally toward the tailings pile.

Sediment-Discharge Relationship

Channel stability is also suggested by a constant bank-full Shields stress parameter with respect to discharge and location along the river. Shields stress is a dimensionless number relating the ratio of flow characteristics to sediment properties. Flow characteristics required to determine the Shields stress parameter are: the fluid density, depth of flow and slope of the hydraulic grade line; and sediment properties include: a representative sediment diameter, submerged sediment unit weight and the acceleration of gravity. A constant shields parameter holds along the 260 km river reach from Rifle, Colorado, to the Potash Mine, Utah (Pitlick and Cress 2002). This consistency implies that regardless of sediment grain size or discharge, the river has adjusted to bank-full width and depth to a constant Shields number that indicates channel stability.

It is also interesting to note that no bedload cobbles or large gravels are currently found downstream of the bedrock controlled at the Portal, i.e. the current downstream bedload is composed of sand (Pitlick 2002, verbal communication). This has not always been the case, as two distinct terrace levels, Qat_4 and Qa_2, as shown by Doelling et al. (2002), are present within 2 miles downstream of the Portal. These facts suggest that the graben (or collapse feature) caused by salt dissolution is currently acting as a trap for gravels and cobbles that normally make up the bedload.

Interpretation of Results From the Summer 2002 Field Investigation

One purpose of the field investigation performed in the summer of 2002 was to gain a better understanding of the ground water regime at the site. Fourteen borings were drilled to install ground water monitor wells and to better understand bedrock lithology across the site. Logs of borings are provided in Lithologic, Well Construction, and Field Sampling Results from the 2002 Field Investigations (DOE 2002). A wood fragment was found at an approximate elevation of 3,852.5 feet (116.5 feet below ground surface, approximately 89 feet beneath the gravel surface) in boring 435 that has been dated with radiocarbon analysis to be 45,340 years old.

River gravels were encountered in a majority of borings advanced as part of the 2002 field investigation, demarking the upper surface of ancestral Colorado River channels across the Moab Project Site. From these data, supplemented with lithologic information from 5 private oil and gas test wells, a surface of the gravel interface is constructed, shown in Figure 4. More confidence is given for the surface defined beneath the site due to a greater amount of data. Other

sources of data used to define the gravel surface south of the river include: (1) logs of private water wells, and (2) the base, or thalweg of the current river channel obtained from river cross-sections surveyed for the HEC–2 analysis performed by Mussetter Engineering, Inc. This information indicates that the gravel surface is continuous beneath the site. This fact suggests slow subsidence of the subsurface (Schumm et al. 2000) and gravel deposition by slow lateral migration of the river channel.

The gravel surface beneath the Moab Project Site possesses undulations in the surface that are interpreted to be abandoned paleochannels of the ancestral river. Also, a depression in the gravel surface exists south of the river beneath the Moab Marsh. This suggests a region of higher salt dissolution. The river will move toward this depression seeking out the lowest topography location.

Sands overlie gravels across the Moab Project Site outside of the current river channel, with a thickness varying up to 65 feet as indicated on Figure 5. This figure represents isopachs of sand over Colorado River gravels developed from pretailings pond site topography. The sands are fine- to medium-grained and free of river gravels. Doelling et al. (2002) has mapped these sands as Qa_2, older alluvium, deposited from the mid Holocene to late Pleistocene (5,000 years to 30,000 years old). Eolian deposition and fluvial deposition from Moab Wash are interpreted to be the origin of these sands. Due to the fact that the sands overlie the gravels, the river could not have been beneath the site during the last 5,000 to 30,000 years ago during sand deposition, assuming dates provided by Doelling et al. (2002) are correct.

Historical Time Scale—Suggested From River Morphology in the Last 120 Years)

Aerial Photographs (60 years previous)

Aerial photographs of the Moab Project Site taken in 1944, 1953, 1980, and 2001 were obtained to assess the historical migration pattern of the Colorado River adjacent to the site. Figure 6 shows outlines of the banks of the river at these photograph dates. Each of the original photographs was at a different scale. Construction of Figure 6 was performed by scanning each photograph, determining common points on each scanned image, and scaling each image to the same scale. Because this process produces some error in the final image, each outline of the riverbank has an associated horizontal error of plus or minus 60 feet.

A first impression of Figure 6 is that the river has not moved appreciably over the last 60 years. The riverbanks are generally in the same location for all time periods. However, it appears that where the river enters the valley, the north bank moved south from 1944 to 1953 and has remained at that location. The southern bank moved south from 1944 to 1953, then north from 1953 to 1980, where it has remained. Approximate river flow rates are also shown on the figure, and there is an indication of channel deepening. Dates of photography for each aerial photograph are shown on the photograph. Flow rates for each photograph are obtained from the Cisco, Utah, USGS gauging station are shown. Flows in 1980 and 2001 are relatively high compared to the earlier flows, but the channel is narrower. This can only occur if the channel has become deeper. This process matches the process of island formation discussed in the previous section (Recent Time Scale).

Adjacent to the tailings pile the river appears to have moved east and south away from the tailings. Vegetation has stabilized a point bar on the right bank of the river adjacent to the

tailings. As mentioned by Schumm et al. (1988) and Leopold and Wolman (1957), vegetation development on bars is an indication of channel stability. The channel has also narrowed in this section, also indicating possible channel deepening.

Riverbanks have moved west as the river approaches the Portal. This movement possibly results from the easterly shift upstream adjacent to the tailings pile. Migration at this location appears to be the largest shift as the river flows through the valley. Migrations of this type are expected of alluvial rivers.

Historical Maps (40 to 100 years previous)

Figure 7 illustrates the outline of the Colorado River banks obtained by digitizing the river location shown on copies of early topographic and cadastral maps of the Moab Valley. Surveys were published on maps from:

- 1880, a cadastral survey (BLM Archives).
- 1912 Colorado River Profiles (Herron, 1917).
- 1924 a cadastral township survey (National Archives).
- 1959 7.5 minute topographic map (USGS).

Absolute bank locations shown on these maps should be interpreted with caution because river flow rates are unknown at the time the land was surveyed. Therefore, conclusions concerning the precise location of banks should be limited to general location and shape.

Review of the figure indicated that the right, or west river bank has not experienced a major shift since the maps were made. The west river bank shown by the 1880 cadastral survey is not complete. Location of the west bank is not shown east of the Courthouse Wash confluence. The west bank that is shown was probably never surveyed because it was unimportant to the small population of Moab. Land interests at that time were east of the river. The remaining outlines of the west bank follow the same trend and appear to possess the same west bank location during high flows. Review of flow records measured and recorded at the Cisco, Utah, gage by the USGS, reveal that a maximum river flow of 76,400 cfs occurred in 1917. Flow has exceeded the bank-full flow of 40,000 cfs 33 times out of 85 recorded flows, indicating the river has flooded 39 percent of the time from 1884 to 2001. Because the west bank has not experienced a major location shift during this time suggests that high flows flood into Moab Marsh preventing westward migration of the river channel.

Long-Term Time Scale—Suggested From Geologic Information

An evaluation of local and regional geology can assist in understanding the potential for channel migration in the long term. Information in Doelling et al. (2002) provides the basis for this discussion.

The Moab Project Site is located at the northwest end of the Spanish Valley in the Paradox Basin. Arches National Park lies adjacent to the site to the north. The Moab-Spanish Valley salt-cored anticline is the dominant structural feature in the region of interest. Sedimentary rocks and structural features along the margins of the anticline provide evidence of upward salt movement (salt diapirism) extending to 300 million years ago and salt dissolution during the last 160 million years (Doelling et. al. 2002). River alignments throughout the last 2 million years,

during the Quaternary Period, provide the longest record of interest to an understanding of potential future river migrations.

The Moab region, as well as the Colorado Plateau in general, is undergoing erosion. Quaternary depositional sites are rare but have been documented in the salt anticlines (Oviatt 1988). In the north end of the Spanish Valley, subsidence caused by salt dissolution is the most likely reason for significant basin-fill surficial sediment accumulation estimated to be mainly of Quaternary age (Doelling et al. 2002). Boring logs from several water wells from the Utah Division of Water Rights reviewed by Doelling et al. (2002), indicate that from the southeast end of the valley at the entrance of Pack Creek to the northwest end where the Colorado River crosses the valley, the thickness of basin-fill increases from approximately 70 to 100 feet to greater than 406 feet. Thickness of basin-fill alluvium at the north end of the Moab Valley is known from drilling performed by Dames & Moore (1982) for Atlas Minerals. The log of boring ATP–1 shows 406 feet of coarse gravels and cobbles, and bedrock was never reached. Because of continued collapse of the boring when traditional mud-drilling techniques were used, the boring was completed using a casing-advance cable-tool method. Continuous samples are recovered using this drilling technique, and the sampled core provides a conclusive record of the lithology.

Additional borings drilled at the Moab Project Site by Canonie Environmental for Atlas Minerals indicate that the thickness of basin-fill sediments abruptly thins to about 100 feet on the north side of the Colorado River. A cross-section from Doelling et al (2002), reproduced as Figure 8, is drawn through the approximate axis of the Moab Valley salt-cored anticline to illustrate thickness of the basin fill. At the northwest boundary of the basin fill, a buried salt-dissolution escarpment is interpreted to have offset and lowered the bedrock surface a minimum of 400 feet (Doelling et al. 2002). The buried escarpment is the boundary separating an area of lesser subsidence northwest of the river from an area southeast of the river where greater subsidence has occurred. Because the river forms an arc as it passes through the valley, the buried escarpment is assumed also to have an arc shape because the highest rate of salt dissolution occurs where the greatest quantity of water exists (Huntoon 1988). This interpretation has been modified to account for the gravel content found in borings drilled by DOE in 2002. However, thickness of the basin fill in the remainder of the valley are still accepted as valid.

Woodward-Clyde Federal Services (1996) estimated salt dissolution rates in the Moab Valley. Dissolution rates are estimated by assuming that basin-fill sediments are accumulating at the same rate at which the basin subsides. Other studies in the Paradox Basin (Colman 1983; Harden et al. 1985; Huntoon 1988; Oviatt 1988) have estimated that salt deformation and subsidence began sometime between the late Pliocene (5 million years ago) and early Quaternary (1.8 million years ago). When subsidence and sediment filling is assumed to have occurred throughout the entire Quaternary, a dissolution rate of 0.23 foot per 1,000 years can be computed. Harden et al. (1985) provide evidence that dissolution could have begun and ended during the Pleistocene, resulting in a dissolution rate of 0.6 foot per 1,000 years. Woodward-Clyde Federal Services (1996) estimated that 54 feet of downcutting of the Qat_3 terrace (Figure 9) had occurred at the north end of the Moab Valley from the time of deposition of the Beaver Basin Formation (Richmond 1962), 12,000 years ago to 30,000 years ago, producing a dissolution rate of 1.8 feet to 4.5 feet per 1,000 years. Discovery of a datable wood fragment in boring 435 can also be used to predict subsidence rates. Two interpretations should be made with from this information. The first is one of uniform subsidence from constant salt dissolution resulted in uniform deposition. Fluvial deposition in an alluvial river occurs due to subsidence because a “space” is created (Schumm et al. 2000). An increase in deposition leads to a greater

width-depth ratio, thus creating a greater chance for lateral migration, and a decrease in erosion potential (Schumm et al. 2000). Thus, assuming uniform subsidence and deposition 89 feet of gravel/cobbles aggraded in 45,340 years, or 89 feet ÷ 45,340 years ~ 2 feet per 1,000 years. This rate corresponds to the lower range of subsidence rates suggested by Woodward-Clyde Federal Services (1996).

A second interpretation that must be considered is that the wood was deposited catastrophically in turbulent flow during a scour event. Terzaghi and Peck (1967) indicate that scour depth in a river channel can be up to 4 times the greatest rise in river level. Historical high water marks are approximately 20 to 25 feet above normal flow level, so scour depths could be on the order of 80 to 100 feet. This fact illustrates that the wood could have been carried downstream from an unknown upstream location deposited under turbulent high flow conditions at any time in the past, from 45,340 years ago to the recent past. Although the age of the wood fragment provides some agreement with other predicted subsidence rates, this computed s subsidence rate is subject to interpretation.

Regardless of whether the long-term or the short-term average dissolution rates are used, the effect of salt dissolution on the alignment and migration potential of the river seems to be mitigated by continued sediment aggradation. This aggradation will force the river to continue to flow in and out of the valley through bedrock controls. If subsidence occurs at a more rapid rate than sediment accumulation, water will accumulate as salt dissolution increases until flow returns through the Portal. Salt-dissolution-induced subsidence has continued episodically from the Pleistocene, through the early Holocene, up to today. There is no reason to believe that it will not continue into the future (Colman 1983; Huntoon 1988; Doelling et al. 2002). Based on discussions presented above, salt dissolution is suggested as the most probable process for base lowering.

Field Observations and Geologic Evidence For Past Migration

River gravels are exposed in the area of the Moab Project Site as shown on Figure 9. Existence of these gravels indicates the presence of former river channels. Numbers shown on the figure represent relative ages, with 1 indicating the oldest channel location. The gravels are on a terrace mapped as Qat_3 by Doelling et al. (2002) near the mouth of Courthouse Wash. Clast lithologies are diverse and consist of Precambrian metamorphic rocks, porphyritic igneous rocks, and sandstones, indicating deposition by the Colorado River. This deposit occurs at an elevation around 4,012 feet, approximately 54 feet above and approximately 1,200 feet north of the present river channel. Based on pedogenic evidence from a soil pit excavated by Woodward-Clyde Federal Services (1996) in the terrace, the terrace age correlates to the Beaver Basin Formation between 30,000 years to 12,000 years ago. This indicates a subsidence, or downcutting rate of 1.8 feet to 4.5 feet per 1,000 years.

Gravels were also discovered in the road cut immediately east of the current parking lot for Courthouse Wash trailhead just north of U.S. Highway 191. These gravels were transported by the Colorado River, or an upstream tributary of the Colorado River, because they are igneous rocks indicating their origin was probably the La Sal Mountains rather than a source in the Courthouse Wash drainage system. Elevation of these gravels is approximately 3,984 feet; approximately 26 feet above and approximately 1,000 feet north of the current river. This elevation and location indicate more recent deposition when compared to the Qat_3 Courthouse Wash terrace deposit. The more recent and lower deposit is south of the older Qat_3 deposit, and

the current river is south of both deposits. Lack of pedogenic information in these gravels requires relative age determination to be based solely on elevation above the current river level and distance below the Courthouse Wash deposit. Based on these elevation differences between the two deposits and the relative age of the Qat_3 deposit, the difference in time of deposition range between approximately 6,000 years to 15,000 years. This suggests that the river migrated 200 feet south in 6,000 years to 15,000 years, or 33 feet to 13 feet per 1,000 years. All positions suggest that the river has migrated south for the last 12,000 to 30,000 years.

Summary and Conclusion

The preponderance of data presented in this discussion indicate that the potential for migration of the river toward the Moab Project Site tailings pile appears unlikely in the foreseeable future. Data includes

- Current river morphology indicates that the Colorado River channel is moderately stable to stable.
- Historical information from aerial photographs and historic topographic-cadastral maps indicate that the river has remained in this condition for the last 120 years, suggesting that catastrophic rapid channel migration is unlikely indicating that all floods have been dissipated by overflow into Moab Marsh.
- Significant movement of the western (tailings side) bank has not occurred.
- As shown on Figure 9, the location and age of river terrace gravels indicate that salt dissolution will continue the trend of river movement southward away from the tailings.
- The Colorado River is not currently transporting a cobble-gravel bedload downstream of the Portal.

Considering the above, the following hypothetical model for the Quaternary evolution of the northern end of the Moab Valley and influence on river migration potential is proposed:

- The ancestral Colorado River has been transporting sediment from the eastern Colorado Plateau and Southern Rocky Mountains during the uplift of these regions during the past 10 million years. This has resulted in incision of the Colorado River along much of its course. Sediment deposition in the Moab Valley created an alluvial river system prone to meandering and avulsion processes. Alluvial controls persist when the base level within the valley conform to inlet and outlet bedrock controls. This is the situation that exists during periods of low salt dissolution. Bedload gravels and cobbles are transported out of the valley as indicated by Pleistocene terraces downstream of the bedrock outlet control at the Portal. Additional evidence of alluvial processes is evident by the undulating gravel surface interpreted as abandoned river channels.

- During periods of high salt dissolution, the base level of the valley subsides faster than erosion of bedrock at the Portal creating a space, a sump, or void, for sediment accumulation. This period is evident by the great thickness (more than 406 feet) of alluvial fill encountered in borings located in the north end of the valley. Periods of sediment transport and sediment accumulation across the valley are episodic based on levels of Pleistocene terraces downstream of the Portal. The elevation and thickness of Pleistocene gravel terraces mapped by Doelling et al. (2002) reveal past times of sediment transport across the Moab Valley.

- Currently, the Colorado River is transporting a sand bedload. This indicates active subsidence of the Moab Valley. The low point of the gravel surface in the Moab Valley is beneath the Moab Marsh suggesting this is the area of highest salt dissolution. Because this is the low point, the river will trend to migrate eastward toward this area.

References

Chorley, R.J., S.A. Schumm, and D.E. Sugden, 1984. *Geomorphology,* Methuen & Co., New York.

Colman, S.M., 1983. "Influence of the Onion Creek Salt Diapir on the Late Cenozoic History of Fisher Valley, Southeastern Utah," *Geology*, 11(4): 240–243.

Dames & Moore Federal Services, 1982. *Ground Water Monitoring Project Uranium Mill Tailings Impoundment, Moab, Utah, for Atlas Minerals,* Salt Lake City, Job No. 05467-030-06, dated October 27.

Doelling, H. H., M.L. Ross, and W.E. Mulvey, 2002. *Geologic Map of the Moab Quadrangle, Grand County, Utah*," Map 181, Utah Geological Survey.

Harden, D.R., N.E. Bigger, and M.L. Gillam, 1985. "Quaternary deposits and soils in and around Spanish Valley, Utah," *Soils and Quaternary Geology of the Southwest United States*, GSA Special Paper 203, David L. Weide ed., Geological Society of America, Boulder, Colorado.

Herron, W.H. 1917. Profile Surveys in the Colorado River Basin in Wyoming, Utah, Colorado, and New Mexico, U.S. Geological Survey Water Supply Paper 396, Government Printing Office, Washington.

Huntoon, P.W., 1988. "Late Cenozoic gravity tectonic deformation related to the Paradox Salts in the Canyonlands area of Utah," in *Salt Deformation in the Paradox Basin,* by H.H. Doelling, C.G. Oviatt, and P.W. Huntoon, Utah Geological and Mineral Survey Bulletin 122, Utah Department of Natural Resources.

Leopold, L.B. and M.G. Wolman, 1957. "River channel patterns: braided, meandering and straight, physiographic and hydraulic studies of rivers," U.S. Geological Survey Professional Paper 282-B, *River Morphology, Benchmark Papers in Geology,* Stanley A. Schumm ed., Dowden Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania.

Mussetter, R.A. and M.D. Harvey, 1994. *Final Report Geomorphic, Hydraulic and Lateral Migration Characteristics of the Colorado River Moab, Utah,* MEI Ref. No. 94-02, prepared for Canonie Environmental and Atlas Corporation.

Oviatt, C.G. 1988. "Evidence for Quaternary deformation in the Salt Valley anticline, southeastern Utah," in *Salt Deformation in the Paradox Basin,* H.H. Doelling, C.G. Oviatt, and P.W. Huntoon, editors, Utah Geological and Mineral Survey Bulletin 122, Utah Department of Natural Resources.

Pitlick, J. 2002. "Geomorphology and Sediment Transport in the Colorado River," Hydrology seminar, presented at Mesa State College, Grand Junction, Colorado, November 19.

Pitlick, J. and R. Cress 2002. “Downstream changes in the channel geometry of a large gravel bed river,” *Water Resources Research*, 38 (10): pg. 12

Richmond, G.M., 1962. *Quaternary stratigraphy of the La Sal Mountains, Utah*, U.S. Geological Survey Professional Paper 324.

Schumm, S.A., M.D. Harvey, and C.C. Waston, 1988. *Incised Channels Morphology, Dynamics and Control*, 1st Printing, Water Resources Publications, Littleton, Colorado.

Schumm, S.A., J.F. Dumont and J.M. Holbrook 2000. *Active Tectonics and Alluvial Rivers*, University of Cambridge, Cambridge, U.K.

Terzaghi, K. and R. Peck 1967. *Soil Mechanics in Engineering Practice*, second edition, John Wiley & Sons, New York, N.Y.

U.S. Department of Energy, 2002. “Lithologic, Well Construction, and Field Sampling Results from the 2002 Field Investigations,” GJO–MOA 19.2.3, prepared for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado, October.

U.S. Department of the Interior, 1926. General Land Office Survey Township 25 South, Range 21 East, Salt Lake Base and Meridian, Utah.

——————, 1880. General Land Office Survey Township 25 South, Range 21 East Salt Lake Base and Meridian, Utah

USGS Moab Quadrangle SE4 7½ minute series Topographic map, scale 1:24,000, Denver, Colorado.

Woodward-Clyde Federal Services, 1996. *Evaluation of potential surface deformation related to salt-dissolution subsidence at the Atlas tailings site, Moab, Utah*, prepared for Smith Environmental Technologies and Atlas Corporation, Final Report, dated January 29.

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FIGURES

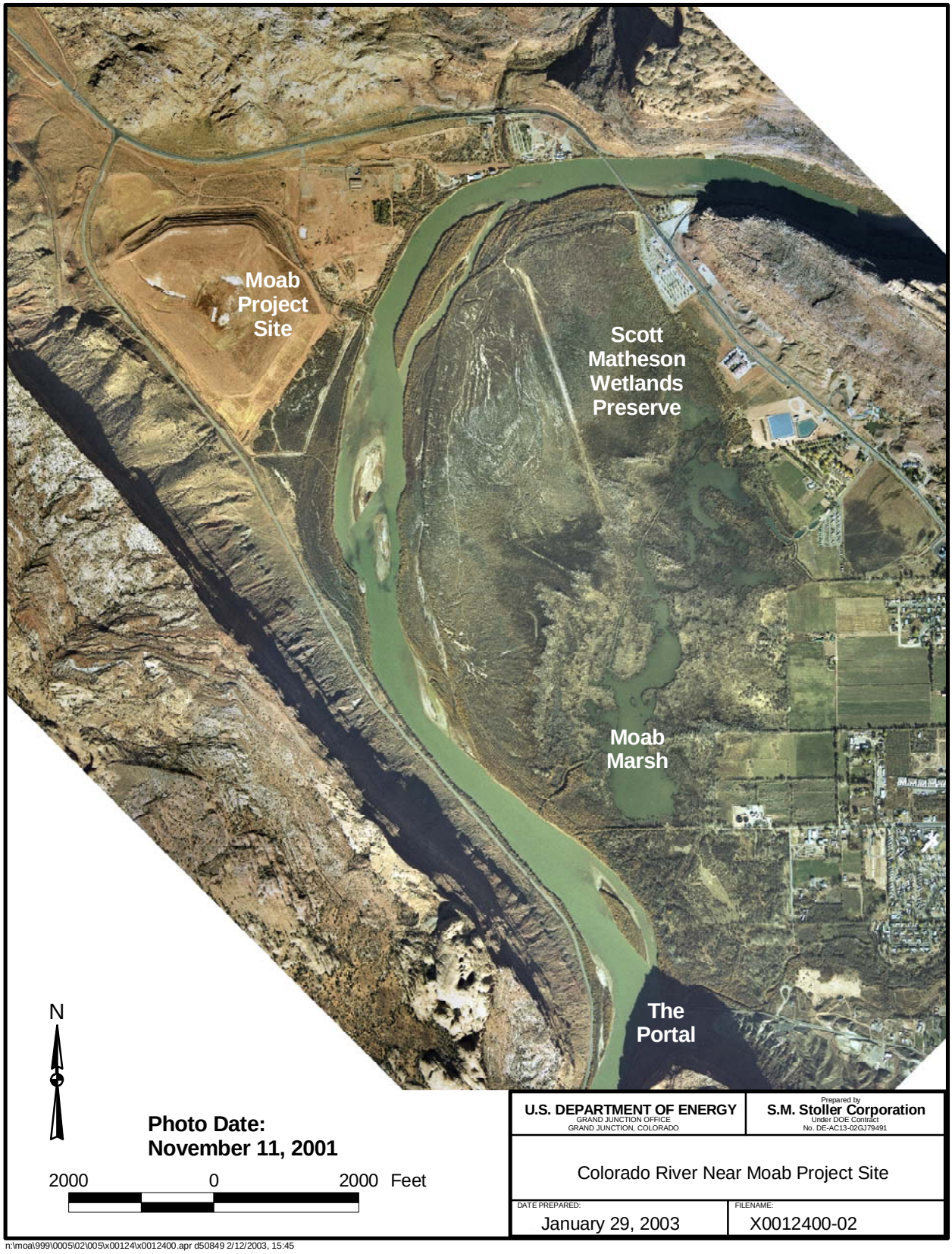

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Figure 1. Colorado River Near the Moab Project Site

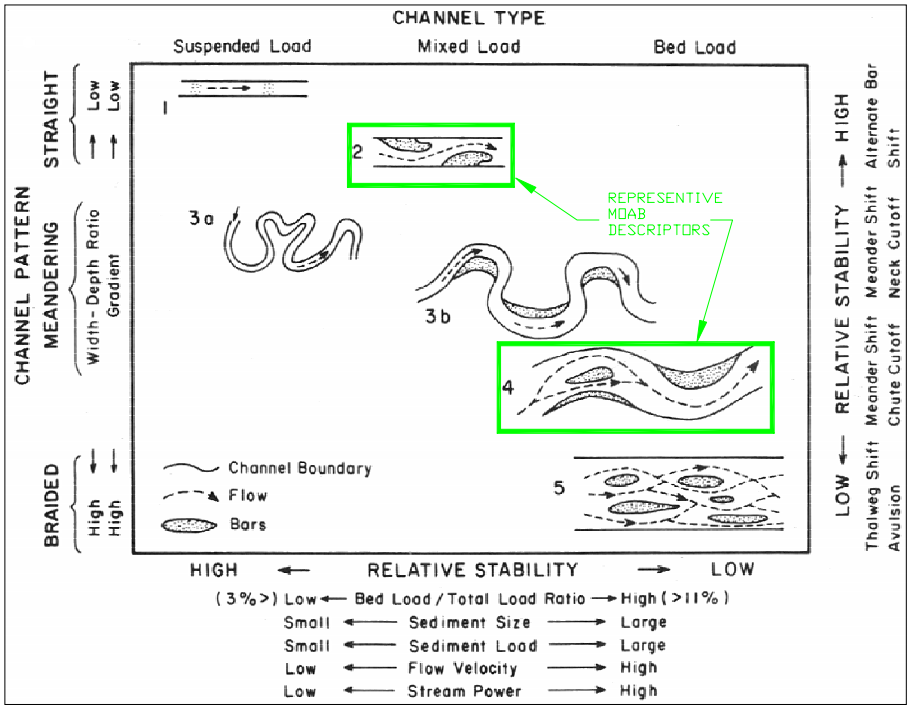


Figure 2. Channel Pattern Classification and Relative Stability
(Chorley et al. 1984, Figure 12.32)

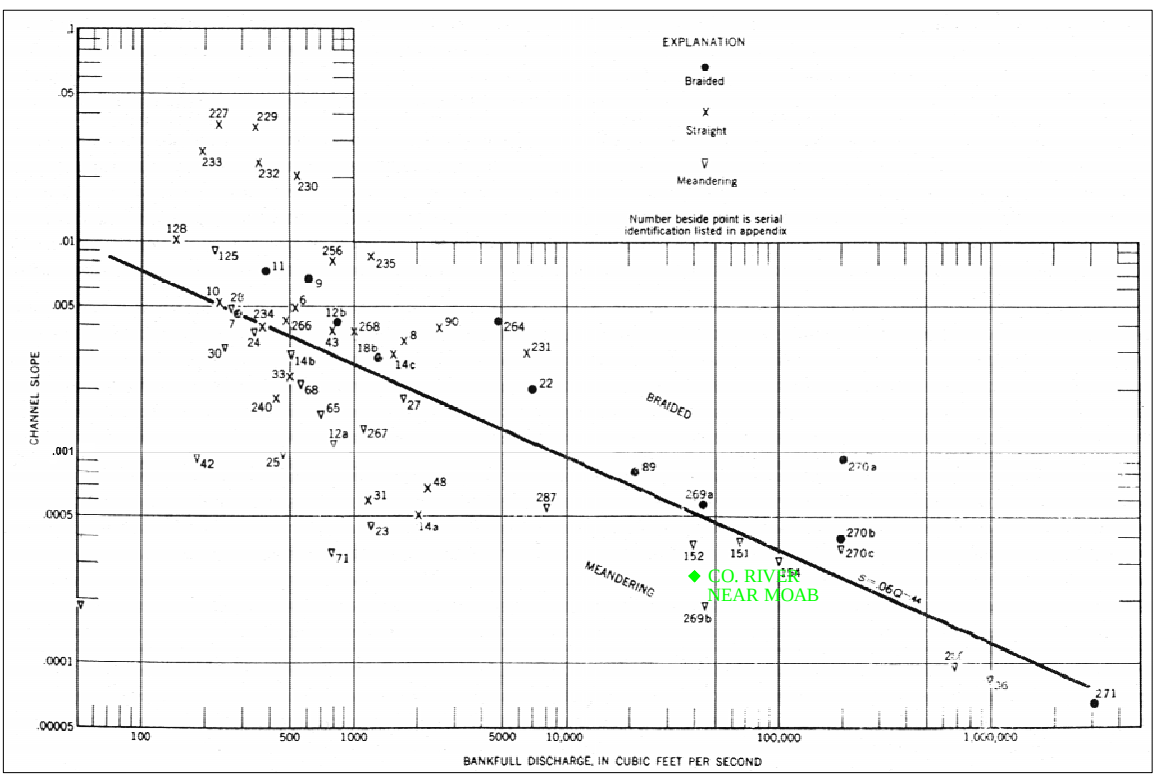


Figure 3. Channel Patterns Related to Bankfull Discharge and Slope
(Leopold and Wolman 1957, Figure 46)

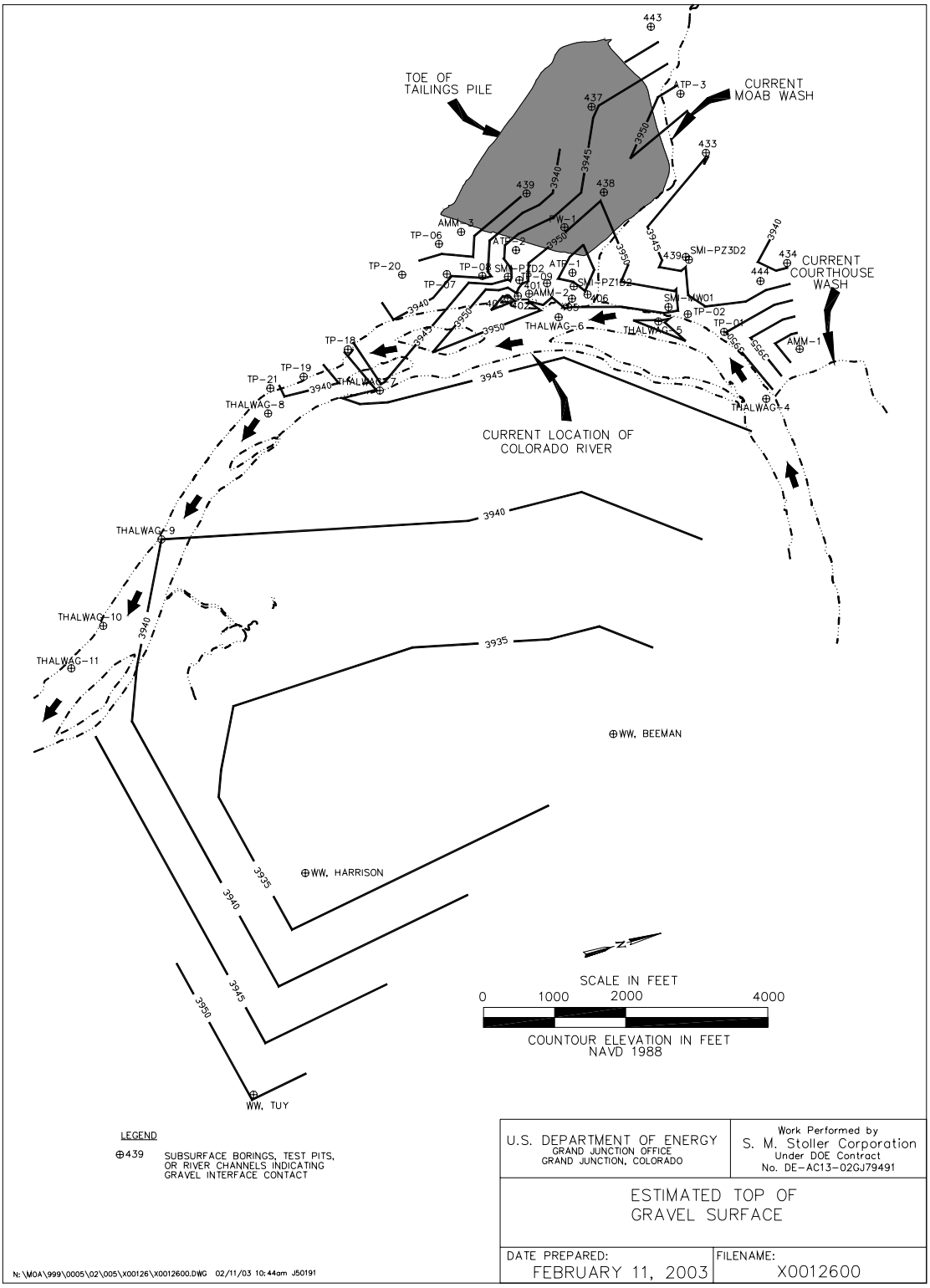


Figure 4. Estimated Top of Gravel Surface

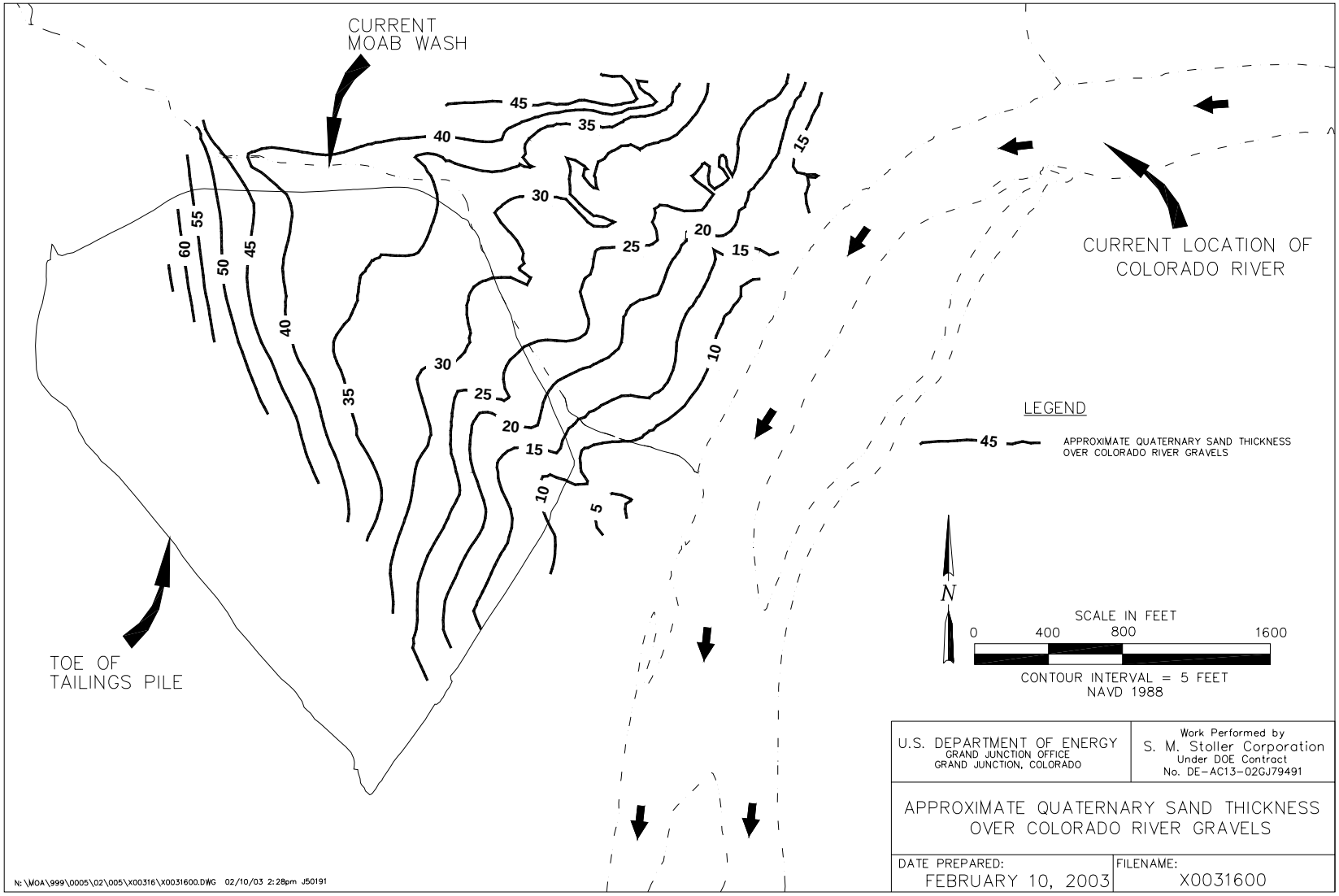


Figure 5. Approximate Quaternary Sand Thickness

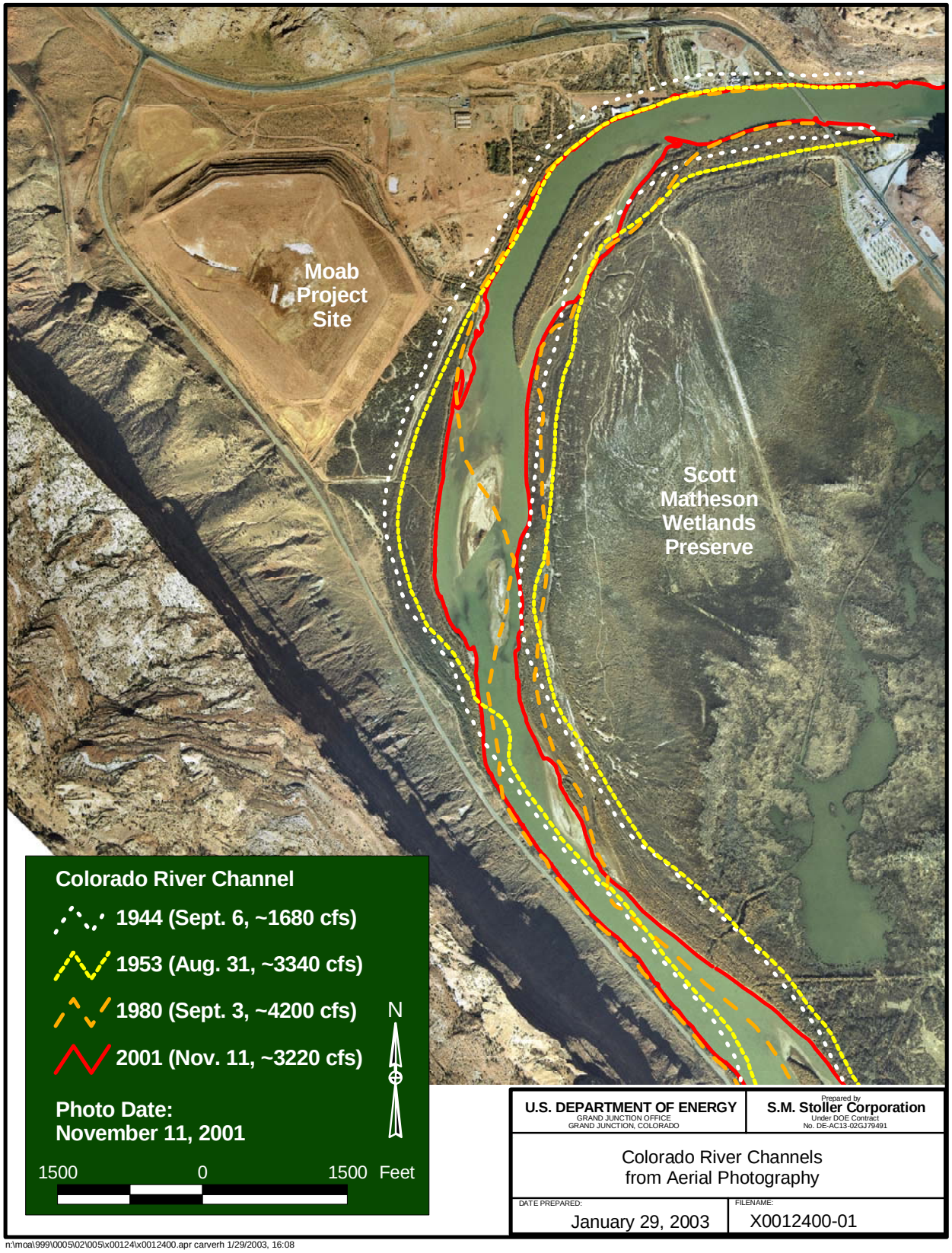


Figure 6. River Channels from Aerial Photography

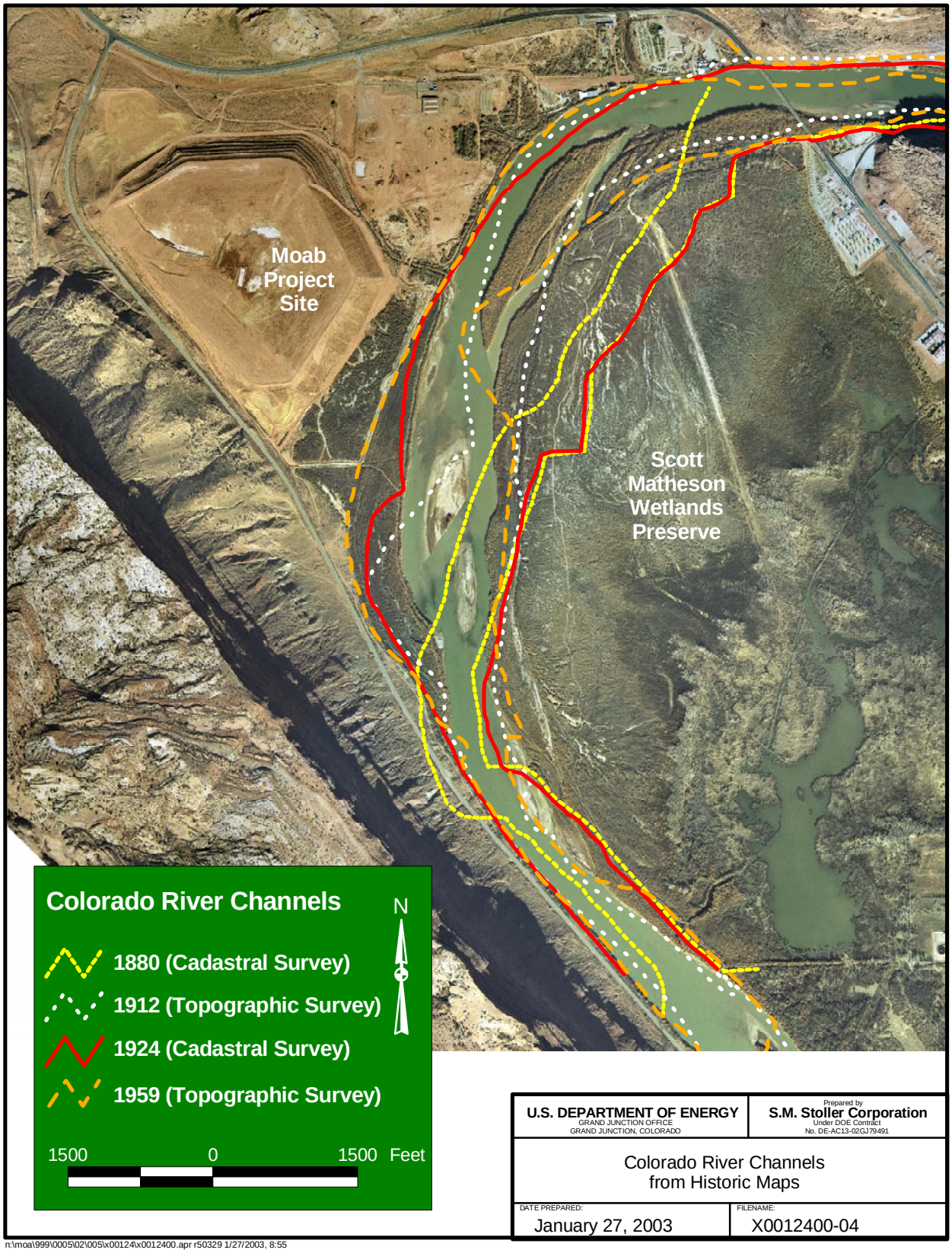
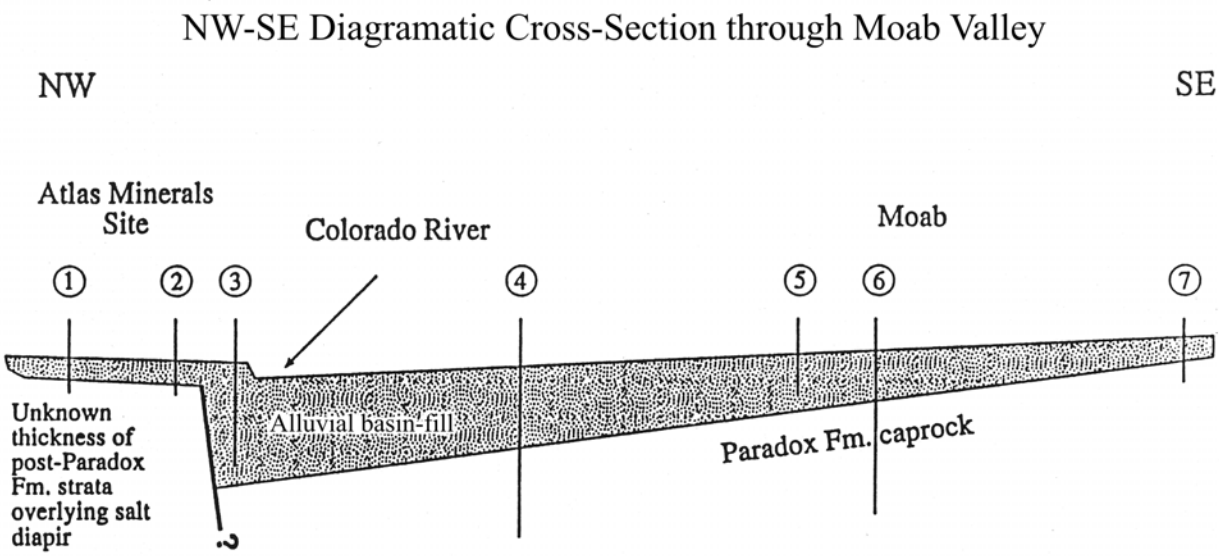


Figure 7. River Channels From Historic Maps



Thickness of alluvial basin-fill in selected wells:	Thickness
1. Atlas Minerals B-4 borehole	99 feet
2. Altas Minerals B-3 borehole	108 feet
3. Atlas Minerals ATP-1 borehole	>406 feet
4. Great Lakes Carbon Corp. brine disposal well	320 feet
5. Water wells in section 1, T.26 S., R.21 E.	>100 feet
6. Western Allied - Big Six Oil Cos. oil & gas well	200 feet
7. Several water wells in section 7, T.26 S., R.22 E.	56-123 feet

Figure 8. NW–SE Diagrammatic Cross Section
(Doelling et al. 2002, Figure 6)

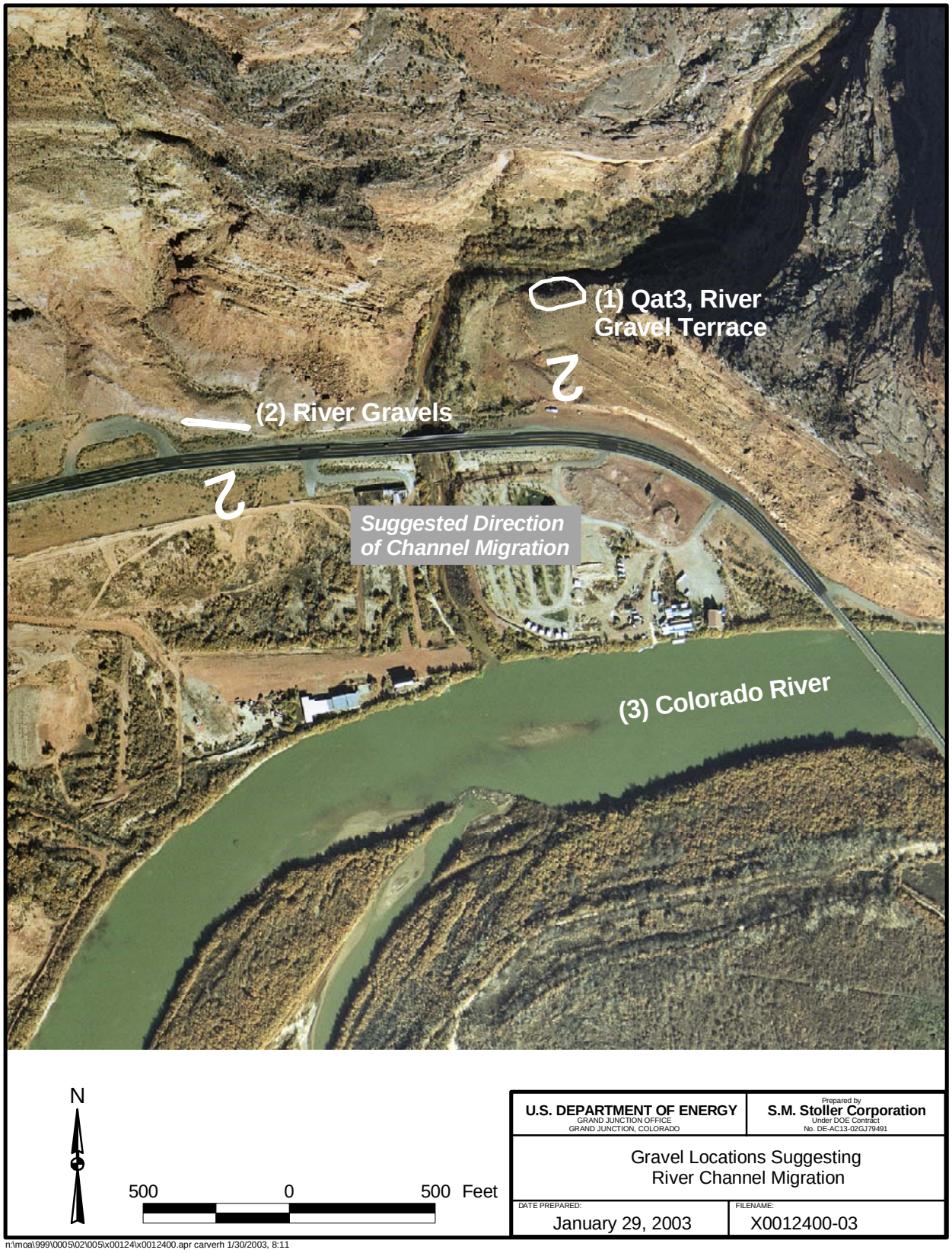


Figure 9. Gravel Locations Suggesting River Migration

Attachment 1

Colorado State University—Independent Review

Colorado State University

College of Natural Resources
Department of Earth Resources
Fort Collins, Colorado 80523-1482
(970) 491-5061
FAX: (970) 491-6307
www.cnr.colostate.edu/ER/

Mr. Toby Wright
The S.M. Stoller Corporation
2597 B3/4 Road
Grand Junction, CO 81503

Dear Mr. Wright: 2 December 2002

I have finished reviewing the seven documents that you sent to me in connection with your project to assess the migration potential of the Colorado River at the Moab Project Site. While reviewing these documents, I have considered two points: potential strengths and flaws in the work done to date, and recommendations for future work. I list the seven documents below, with a brief summary of contents relevant to these two points.

1) 1994 Mussetter Engineering report: The consultants evaluated the potential for lateral channel migration toward the Atlas Corporation tailings pile. They considered lateral migration to be unlikely because: bedrock outcrops upstream and downstream from the project site "fix" the channel in place; the marsh on the inside of the channel bend dissipates flow energy during floods; the downstream hydraulic constriction at the Portal creates a backwater effect that reduces flow energy during floods; and the gradual progradation of the alluvial fan on which the tailings pile rests counteracts lateral channel migration. The consultants used the 1d hydraulic model HEC-2 to simulate hydraulics for flows up to the NRC PMF of 300,000 cfs.
2) 1996 Woodward-Clyde reports: The consultants evaluated seismic and salt dissolution hazards at the site. They found evidence of primarily pre-Quaternary movement along the fault, which they concluded did not pose a hazard within the 1,000 year timeframe for the project site. They also found evidence of Quaternary salt dissolution near the site, and they judged that there was a good potential for this dissolution to continue.
3) 2002 DOE report: The authors of this report concluded that the Colorado River is moving away from, and will continue to move away from, the tailings based on: considerations of river morphology and stability; analysis of air photos since 1944; analysis of site stratigraphy; and inferred conditions of salt dissolution.
4) Excerpted pages from an NAS report: A review panel convened by the NAS expressed concerns about stability at the project site related to lateral migration of the river associated with normal meander bend evolution, or with discharge fluctuations caused by dam failure or Quaternary climate change.

5) I have also reviewed the 2002 DOE report on field geologic sampling results, and the 2002 7.5' geologic quadrangle of the region.

Having reviewed these documents, I see no flaws in any of the studies or reports presented to me for my review. With respect to the first document, the HEC-2 model was used appropriately, and constraints related to the model's assumption of rigid boundaries and 1d flow were acknowledged by Mussetter Engineering. I am not convinced that the upstream and downstream bedrock points would so constrain the channel as to prevent lateral migration into the tailings pile, but I think that the combination of an extensive marsh, the downstream hydraulic constriction at the Portal, and the presence of an alluvial fan below the tailings pile (as indicated by extensive sand deposits not associated with the Colorado River) will together prevent catastrophic lateral migration of the channel into the project site, even during very large discharges. I think that the possibility of gradual lateral channel migration remains, but this could presumably be addressed with additional bank stabilization and protection measures, as needed.

The seismic hazards at the site appear to be negligible, but the potential for local subsidence associated with salt dissolution does appear to be a serious concern in terms of how it may influence lateral river migration. Again, such subsidence would not likely be catastrophic, but rather gradual, as would any channel response to the subsidence. This would allow time for remedial, in situ engineering measures to be undertaken to restrict lateral river migration toward the tailing pile, if necessary.

The analyses in the 2002 DOE report seem sound, and the interpretations reasonable, but a trend in river migration through time does not in and of itself guarantee that the trend will continue. I think that the specific hydraulic controls at the site (marsh, backwater, etc. as mentioned above) are stronger lines of evidence that lateral channel migration is unlikely to remove substantial portions of the western river bank and tailings pile during a flood.

In summary, I think that some of the concerns raised in the NAS report are important. For reasons summarized above, I do not think that continued lateral migration of the channel at the project site poses a hazard of catastrophic erosion. I also do not think that the concerns regarding erosional stability with respect to large flood discharges are relevant. The modeled PMF of 300,000 cfs is highly unlikely to be exceeded, even if a dam were to fail upstream, or discharge were to fluctuate in association with climate change. Paleoflood studies along the Colorado River downstream from the project site, in Grand Canyon National Park, record a maximum discharge of almost 500,000 cfs during the last 4,5000 years (O'Connor et al., 1994). Considering that the project site at Moab is above the junction with the Green River, 300,000 cfs is a conservative value for the PMF. My evaluation does not attempt to address the NAS concerns regarding slope stability or ground water impacts from flood inundation.

My recommendations for futher work at this point focus on *further modeling of hydraulics and channel processes at the project site.* When the 1994 Mussetter study

was done. HEC-2 was "state-of-the-art" for modeling river hydraulics, despite the simplifying assumptions of 1d flow and rigid channel boundaries. This resulted in part from the lack of commercially available 2d models. Such models are now readily available and being increasingly used for commercial as well as research applications (examples of models include RMA2 and HIVEL2D). These models continue to assume rigid boundaries, and they require a substantial effort of time and investment by the user; detailed field surveys are necessary to construct a 3d channel mesh for use in modeling, for example, and field data of water-surface elevations at varying discharges are necessary to adequately calibrate model parameters. However, these 2d models would provide a much more accurate assessment of the complicated flood hydraulics at the project site, where flow separation is likely to be very important in controlling the hydraulic forces exerted against the outer bank of the channel meander and, at high discharges, against the riprap along the tailings pile. This suggestion represents a refinement on existing work, but if time and budgetary constraints are significant, I do not think this suggested refinement is critical to the site evaluation. In addition to using commercially available 2d models, long-term models of river evolution and lateral migration could be very useful in evaluating different scenarios at the project site. For example, if subsidence continues, producing aggradation in the vicinity of the project site, this might enhance sinuosity and lateral migration of the river. I am not aware of any commercially available long-term models of river evolution, so this approach would involve working with a researcher who had designed such a model. The model I am most familiar with was developed by Professor Alan Howard at the University of Virginia.

In conclusion, it is very unfortunate that a uranium mill tailing site sits within the valley bottom along one of the major rivers of the American West. However, given the large costs associated with moving the hazardous material, I think that the risks posed by lateral river migration at the site can be addressed with in situ engineering measures that limit gradual lateral erosion by the Colorado River if this begins to threaten site stability.

Reference cited: J.E. O'Connor, L.L. Ely, E.E. Wohl, L.E. Stevens, T.S. Melis, V.S. Kale and V.R. Baker. 1994. A 4500-year record of large floods on the Colorado River in the Grand Canyon, Arizona. The Journal of Geology, v. 102, pp. 1-9.

Sincerely,

Ellen Wohl

Ellen Wohl
Professor of Geology

Attachment 2

U.S. Army Corps of Engineers Review

DEPARTMENT OF THE ARMY
U.S. ARMY ENGINEER DISTRICT, SACRAMENTO
CORPS OF ENGINEERS
1325 J STREET
SACRAMENTO, CALIFORNIA 95814-2922

REPLY TO
ATTENTION OF

August 14, 2003

Regulatory Branch (200375275)

Mr. Joel D. Berwick
U.S. Department of Energy
Grand Junction Office
2597 B 3/4 Road
Grand Junction, Colorado 81503

Dear Mr. Berwick:

We are responding to the U.S. Department of Energy (DOE) written request for comment on the Moab Mill Tailings Project. The project is located adjacent the Colorado River, northwest of the City of Moab, Grand County, Utah.

In accordance with Section 404 of the Clean Water Act, a Department of the Army permit is required for any discharge (including mechanized land clearing) of dredged or fill material in waters of the United States. Within the context of Section 404, "waters of the United States" are defined as the territorial seas; perennial and ephemeral streams; lakes, ponds, impoundments; and wetlands. The project site is also located within a declared navigable reach of the Colorado and is subject to Corps of Engineers regulation under Section 10 of the River and Harbor Act. Federal law requires that any individual or entity proposing to discharge into waters of the United States obtain a Department of the Army permit **prior** to commencing such work. To aid the applicant and to ensure issues within the Corps of Engineers jurisdiction are adequately disclosed, we hereby agree to accept cooperating agency status on development of the Moab Project Environmental Impact Statement.

Our technical review of EIS documents will be limited to the resources available at the Colorado/Gunnison Basin Regulatory Office. The locations of aquatic resources have been addressed in the preliminary working draft EIS Chapter 3, and the Corps of Engineers will verify the presence of jurisdictional aquatic resources for project alternatives prior to release of the preliminary Draft or Draft EIS, as appropriate. Our providing of 100 and 500 hundred year flood plain maps will be limited to a research of currently available data, which has probably already been obtained by DOE or their consultants.

We do not have local capability to produce river migration technical documents, and our involvement will be limited to review and comment on DOE/DOE consultant generated documents. In that regard, we offer the following comments on the Migration Potential of the Colorado River Channel Adjacent to the Moab Project Site, Letter Report dated February 2003, Revision I:

1. As a general comment, The Letter Report as presented would provide sufficient information for issuance of a Department of the Army permit, with some minor clarifications, due to the administrative and physical oversight capability of the DOE.

2. Page 3 of the report discussions relative to the figures cited, especially Figure 2, are inconsistent. This may not be extremely important, however, since virtually all report discussions concern long-term geomorphology and short-term hydraulic events.

3. A key consideration in short-term major hydraulic events is the inflow and outflow bedrock geologic controls within the project area. We believe that the tailings pile is not likely to be jeopardized by typical bankfull flow, but, a combination of a high flow river event plus high tributary flow could inundate the entire project area. Under that scenario, the questions would be whether the outlet control was sufficient to handle the hydraulic event, and whether debris and sediment would block outflow.

4. Water flows and engorgement of the tailings site could result in uplift pressures of soil particles, making them vulnerable to movement by low velocities and by higher velocities as impounded water outleted the project site. The question would be whether an in-place tailings pile would be affected.

5. The text interpretation does not address catastrophic events, which would be more likely to affect the project site than normal high flow. It is likely that the development of Matheson Meadows wetlands and riparian areas resulted from some major event(s) that resulted in the deposit of finer grained materials with implied standing water or slow over-bank sheet flows.

6. It should be noted that the Grand Junction process site appeared to be located in a stable geomorphic area, however, river scour and downstream movement of tailings did occurred at the site during high flow events.

7. Our review of the project site indicates, that with proper stabilization of an inplace tailings pile, only a major sustained bankful discharge event would cause lateral migration sufficient to affect the project site.

We appreciate the opportunity for cooperating agency status, and look forward to participating in development of the EIS. We regret that our technical involvement can not provide more substantiative comment, however we can assure prompt processing of the Department of the Army permit, if required. We have assigned number 200375275 to this project. Please refer to this number if a Department of the Army permit is required on this important project. If you have any questions, please contact me at telephone 970-243-1199, extension 11.

Sincerely,

Ken Jacobson
Chief, Colorado/Gunnison Basin
Regulatory Office
400 Rood Avenue, Room 142
Grand Junction, Colorado 81501-2563

Copies Furnished:

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Daren Rasmussen, Utah Division of Water Rights, 1594 West North Temple, Suite 220, Post Office Box 146300, Salt Lake City, Utah 84114-6300
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