V. Site-wide Threats and Considerations

Part V.1. Environmental monitoring

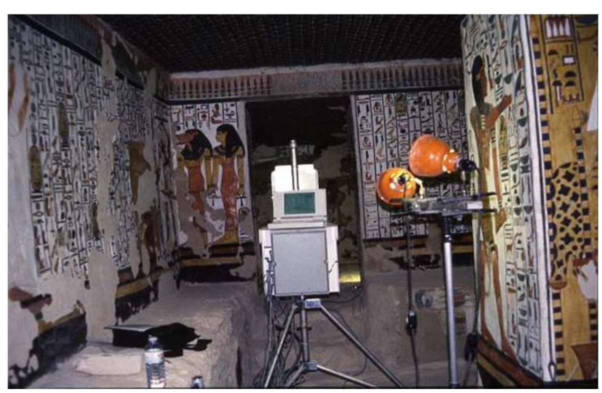
Introduction

Of the many factors that cause deterioration of archaeological sites and monuments, climate is critical. Knowledge of climatic conditions is thus fundamental to efforts to protect and preserve a site. Extraordinary as it may seem, there appears to be no quantitative climatic data for the Theban necropolis nor any permanent meteorological station on the West Bank; and this after more than a century of archaeological investigation of the many hundreds of pharaonic tombs and temples by long-established archaeological missions as well as the national antiquities authority itself.

That the area is excessively arid throughout the year and extremely hot in summer is the extent of anecdotal information on climate. Yet there is quite extensive comment in the literature on the archaeological evidence for flash floods that have devastated the tombs of the Kings and Queens Valleys. Most recently, in 1994, damaging floods occurred on the West Bank but no rainfall data exists. It is surprising, therefore, that an institutionalized meteorological station has not been established in the archaeological areas of the West Bank. The only nearby station is at Luxor airport, where rainfall patterns are different than in the Theban mountains (as discussed in Section 2 dealing with flood control in the Queens Valley).

When considering microclimate within tombs the situation is similar. Previous measurements of humidity and temperature have typically been made using hand-held instruments over short time periods. These provide little more than a snapshot view of conditions which change with season, natural ventilation, and due to the influence of visitors to tombs.

It was clear that the need existed in the Queens Valley project to acquire comprehensive external and internal environmental data in order to understand the real climatic threats to the antiquities and to be able to design and implement measures to counter or mitigate both natural and human impacts. Limited climatic monitoring in the Valley began in connection with the GCI's project (1986-1992) for the conservation of the tomb of Nefertari (QV 66). An autonomous monitoring station was installed at the entrance to QV 66 in August 1991 to record air temperature, wall temperature, relative humidity, carbon dioxide concentration inside the tomb, and visitor entry/exit count; and for the exterior temperature, relative humidity, rainfall, and solar radiation. Wind direction and wind speed sensors were added to the station in May 1992. The effects of visitation on the tomb's microenvironment were also studied through six controlled experiments involving people in the burial chamber, conducted over a year to evaluate seasonal variations. The findings are summarized below.

The environmental monitoring station installed at the tomb of Nefertari (QV 66) in August 1991. Left image shows a solar panel and sensors installed on a tripod just outside the entrance arch. Right image shows station's datalogger in the burial chamber.

Climate of the Queens Valley

Climatologically, the year can be divided into winter and summer. November through March may be considered winter, with the daily average air temperature recorded by the GCI's station between the low 20s and high 10s °C. The lowest air temperature drops to 5°C. The winter average humidity is higher than in summer and ranges between 30 - 40% RH. It can reach as high as the mid 80s% RH in early mornings as well as during drizzling rain, and drops to 5% RH in the afternoon on hot, dry days. Daily swings of humidity are larger in winter than in summer. As stated, it seldom rains in the area. But, rain, whose amount is highly variable, mostly occurs between October and May.

The summer, from April to October, has daily average air temperature ranges from the high 20s to the mid 30s °C. Peak temperatures can reach the mid 40s °C. The humidity averages between the high 10s % and the low 20s % with the daily swing between about 10 and 35% RH. The daily maximum seldom reached 50% RH in summer, but the minimum often drops below 10% RH on sunny afternoons. Although the relative humidity is lower in summer than in winter as described above, the absolute moisture content (as distinct from RH which is temperature dependent) in the air is 30 - 40% more in summer due to higher temperatures. Wind blows from the southwest and northeast with speed averaging 6-7 km/hr throughout the year. Occasional strong winds, over 30 km/hr, blow from the southwest in summer.

Microclimate of QV 66

Toward the end of the project for the conservation of Nefertari's tomb, environmental monitoring was undertaken in order to understand the microclimate within the tomb and its relationship to deterioration, including the effects of exterior climate and visitation. At that time it was expected that the tomb would not be opened to tourism because of concerns that visitation might accelerate deterioration, though this expectation subsequently proved likely to be wrong based on condition monitoring of the paintings over a number of years. Below is a summary of the findings of the first period of monitoring, followed by further monitoring in 1996-1997 when the SCA opened the tomb to daily visitation, and of the current monitoring results undertaken for the Queens Valley project.

<u>August 1991- September 1993</u>:
Monitoring concluded in September 1993 with the following findings and recommendations:

• The natural (stable) condition of QV 66 was around 29°C and 45 - 50% RH with the entrance door vent holes in the bulkhead sealed; that is without natural ventilation via the door.

• Natural ventilation through the entrance and its bulkhead was identified as the source of the seasonal variation of humidity which ranged from 18% RH in winter to 40% RH in summer.

• Therefore, it was recommended, in order to maintain a more stable microclimate, the tomb's entrance should be better sealed by means of plugging the ventilation holes in the bulkhead.

• The microenvironment of the tomb was sensitive to the effects of visitation, as well as to the site climate.

• Visitors produced humidity and carbon dioxide (CO_2) increases of 0.5% RH/hour/person and 50 ppm/hour/person, respectively, in the burial chamber. After visitors exited the tomb, temperature recovered almost immediately, but the recovery of relative humidity and carbon dioxide levels were much more protracted.

• Natural ventilation through the tomb's entrance removed moisture from the tomb generated by visitors, but the rate depended on seasonally varying ventilation rates.

• With the door open, a natural ventilation rate of less than one air change in 7 hours (which means it takes up to 28 hours to dissipate 94% of any visitor effects) was found in winter months, and more than 24 hours (which means it would take more than 4 days to dissipate 94% of visitor effects) in the summer.

Therefore, if the natural stable environment of the tomb is to be maintained, in the absence of mechanical ventilation, only limited numbers of visitors can be allowed in the tomb at any one time and then only in winter months, and no visitors should be allowed in the tomb in summer months.

February 1996 - February 1997:

In 1995, policy changed with respect to visitors to the tomb. The SCA installed a wooden viewing platform, lighting, and a mechanical air extraction system (probably effective up to one air change per hour) for ventilating QV 66, which was officially opened to visitors on November 4, 1995. Although the SCA limited visitors to 150 per day, year-round visitation was permitted. Environmental monitoring was resumed by the GCI in February1996 for a period of one year to evaluate the impact of daily visitation with mechanical ventilation in operation. Unfortunately, the monitoring had missed the 1994 rain that resulted in flash flooding in the Valley (QV66 was not affected) since the event fell between the two monitoring periods. Results were as follows:

• Most visitors arrived before noon resulting in continuous visitation of 20-30 groups in mornings.

• Greater effects of visitation on the tomb environment were observed in the funerary chamber and a side chamber connected to it (Chambers C and G) than the burial chamber (Chamber K).

• In February the baseline temperature dropped by 1.5°C from the undisturbed tomb temperature of 29°C, and daily minimums were as low as 27.2°C. In October the baseline temperature rose by 1°C and reached 30°C with daily peaks reaching 31°C.

• Relative humidity was approximately 38% in August to 20% in February; however, RH values as low as 14% occurred in winter. Daily variations were less than 10% for most of the period.

• Overnight values of carbon dioxide were about 700 and 1200 ppm in winter and summer, respectively. The natural carbon dioxide concentration in the atmosphere is 350 ppm.

• In the burial chamber the concentration of carbon dioxide mostly remained at less than 1500 ppm; however daily peaks due to visitors were 1500 to 3000 ppm in side Chamber G.

These observations lead to the following concerns:

• The rate of mechanical ventilation was minimal but adequate for the visitation load, with the exception of Chamber G; however, the distribution of air extraction points within the tomb was poorly designed.

• Ventilation was effective in limiting humidity to less than 55% in summer; however, the ventilation caused a drop to 14% in winter which may result in desiccation of the wall paintings, with unknown effects, but possible micro-cracking of the surface if any gypsum in the plaster were to change into anhydrite.

• Another concern was the significantly increased daily and annual temperature variations. If the ventilation rate is increased to prevent CO_2 exceeding 1000 – 1250 ppm, which would be an acceptable level of carbon dioxide, the temperature will increase by a few degrees because of the influx of warm outside air. Impacts of the larger temperature variations on the wall paintings should be investigated.

Since February 2009:

The environmental monitoring station for the site climate was re-installed near the entrance of QV 66 in February 2008. The principal purpose of the resumption of site monitoring was to obtain quantitative data in the event of rainfall. A year later, in February 2009, a temperature and relative humidity sensor and a visitor counter were placed in the tomb to resume monitoring the tomb's microenvironment and to analyze impacts of the current visitation pattern. Prior to this time SCA policy had changed again with significantly higher ticket prices and commensurately fewer visitors. CO_2 concentration is not monitored since visitor numbers are small and an extraction ventilator operates whenever visitors are in the tomb. Data from February to November 2009 are as follows:

• Temperature: Monthly average ranged from 29.1°C in March to 29.6°C in September, October, and November. Daily variations were less than 0.5°C. The highest was 30.1°C in October and November and the lowest was 29.0°C in March and April.

• Relative humidity: Monthly average ranged between 17% (February and March) and 31% (September and October). The highest was 37% in October and the lowest was 15% in March. Daily variations have been less than 10% and mostly less than 5%.

• Visitation: The visitor counter at the entrance to the tomb recorded less than 2600 visitors between February and November 2009 (fewer than 10 visitors/day on average). The majority was less than 20 visitors in a group. (30-50 visitors were counted on four occasions; however, the sensors may have been interfered with on those visits.)

In summary, the conserved wall paintings in QV 66 were exposed to large daily variations of temperature and humidity for several years during the period of visitation from November 1995. Currently variations of both the temperature and humidity are significantly less than previously. This is due to the changed policy of the SCA in which the tomb is closed to visitors with the exception of pre-booked tour groups. Therefore, we expect no additional impact on the wall paintings due to the current sporadic and light visitation load. However, the existing air extraction ventilation system will need to be redesigned to effectively dilute the impacts of visitors with the least volume of ventilating air. A supply air ventilator with a dust filter should be added to improve the air quality of the make-up air. A large amount of dust and lint from visitors' clothes has accumulated on the floor throughout the tomb. The dust becomes airborne when visitors enter the tomb (air motion generated by visitor movements), therefore, dust and lint should be removed (vacuumed) from the tomb to improve the air quality and because of fire danger.

Microclimate of QV 44 and QV 55

Environmental monitoring in QV 44 and 55 also started in February 2009 using self-contained temperature and relative humidity data loggers in the burial chamber of each tomb. These tombs receive heavy visitation. Data was downloaded to a personal computer during each campaign for analysis. Dust deposition was measured at the same locations. In addition, a portable station with temperature, humidity, and CO_2 monitoring capabilities was used in these tombs to record detailed daily environmental changes during some of the campaigns. Rates of natural ventilation of the tombs were also measured in mid-summer and early winter. Data from February 2009 to November 2010 are as follows.

• Temperature: Monthly averages ranged from 27.4°C in March to 31.8°C in October. Daily variations were 4-5°C in winter to about 2°C in summer. The highest temperature was 33.7°C in October and November, and the lowest was 23.5°C in February.

• Humidity: Monthly averages ranged between 24% RH in March and 33% RH in October. Daily variations have been 10-25% RH throughout the year. The highest humidity was 70% RH in March, and the lowest was 14% RH also in March.

• Natural ventilation: Natural ventilation rates ranged from 1.2 to 4 air changes per hour during summer and winter (late November), respectively. These smaller and flatter tombs (in comparison to QV 66 whose open-door natural ventilation rates ranged from 0.1 to 1.3 air changes per hour for summer and winter, respectively) have faster responses to the outside climate generally resulting in much higher rates of natural ventilation in both seasons.

• CO_2 concentration: The CO_2 concentration reached 3000 ppm during a number of measurements performed in the tombs in winter. The high CO_2 concentrations are attributable to high visitor loads in the small tombs. However, in summer it remained below 1500 ppm due to significantly lower visitor numbers. Both tombs' CO_2 levels returned to ambient concentration (350 ppm) by the following morning in both seasons.

• Dust (particulate deposition): The calculated deposition rates over one year on horizontal surfaces ranged from 175g/m^2 in QV 55 to 50 g/ m^2 in QV 44. Particle size ranged from 0.3 to 100 μm. About 30% of the particles were less than 2.5 μm, and 60% less than 10 μm in size. Mineralogically the dust was mainly clay and calcite.

In summary, large daily variations were recorded in both the temperature and humidity in QV 44 and 55 throughout the year. These result from high visitation in these small tombs. Therefore, it will be necessary to operate adequate mechanical ventilation systems to reduce the effects of visitors during operational hours for both protection of wall paintings and visitor comfort. The systems should have both an extraction fan and a supply fan with a dust filter to limit transport of dust into the tombs. However, it was found that the moisture, heat, and CO_2 dissipated overnight and did not accumulate in the tombs. This is attributable to a relatively high natural ventilation rate of these tombs during the night. As noted in QV 66, a large amount of dust is found on the floor throughout the tombs. This should be removed to reduce airborne dusts resulting from disturbance by visitors.

Summary Conclusions

The climate of the Queens Valley and interior climates in QV 44, 55, and 66 have been recorded, analyzed and compared. The tombs' interior climates are greatly affected by both the site climate and visitors. In QV 66, due to the current small number of visitors, relatively large tomb size, and the use of a mechanical ventilation system, effects of visitors have been smaller than those recorded during the 1996-1997 monitoring period. However, the existing ventilation system will need to be re-designed for improved efficiency. A large amount of dust has accumulated on the floor throughout the tombs; therefore dust should be removed periodically. Dust also deposits on the wall paintings and protective glass screens which then require cleaning. This operation, carried out sporadically by unskilled workers, is hazardous to the wall paintings as mechanical damage is inevitable.

Microclimates in QV 44 and 55 are rapidly affected by the large numbers of visitors and the lack of mechanical ventilation. The effects have been documented as high levels of temperature, humidity, and CO_2 as well as their large daily variations. It is necessary to limit the number of visitors and install a filtered ventilation system to mitigate the effects. Due to the large seasonal variation of the site climate and small tomb sizes, careful consideration is needed to design a safe (for both wall paintings and visitors) and efficient ventilation system for each tomb.

It is essential to establish acceptable target ranges of temperature, humidity, CO_2 and dust levels for preserving the wall paintings as well as ensuring visitor safety and comfort in the tombs in order to design a suitable environmental management strategy. Through monitoring, we have documented ranges of microclimate conditions to which the wall paintings have already been exposed in the tombs. Fortunately, exposure to extreme conditions has been brief. Determination of a target range of climate may require a set of laboratory experiments to provide understanding of the thermo-hygrometric responses of the wall painting materials. Laboratory analysis should include thermal and hygric dilatation measurements of the limestone, plaster, and wall painting layers. Based on data for QV 66, prior to the tomb having been opened to visitation, that is in the stable, or slow seasonally changing, conditions of relative humidity and temperature, initial environmental requirements could serve as the baseline for such laboratory investigations. Once the target range has been established, the number of visitors and a ventilation rate could be balanced to maintain preservation conditions for a variety of outside conditions.

Part V.2. Assessment of Flash Flooding

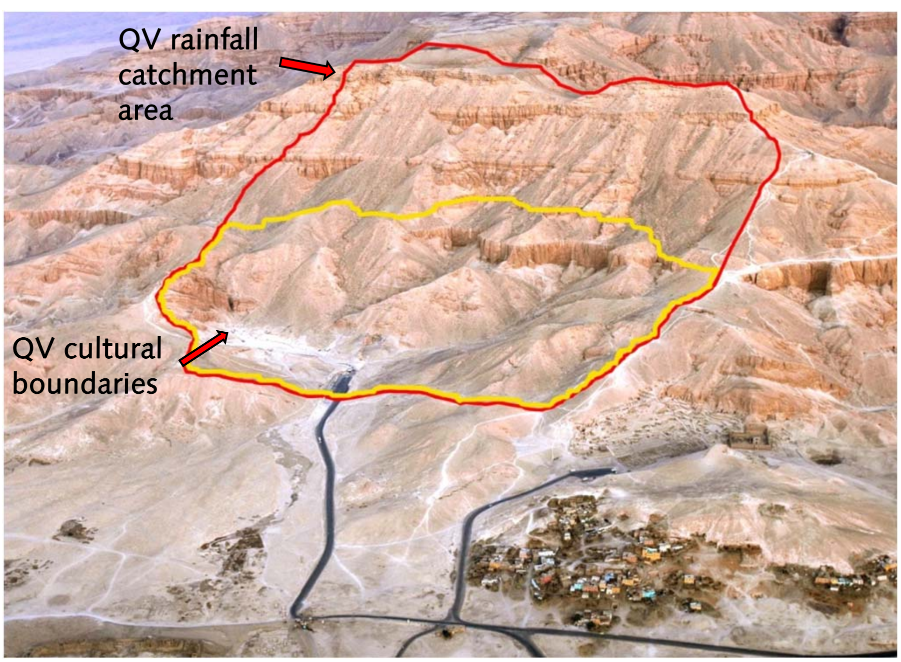
Introduction

History has shown that, like at the Valley of the Kings, no other threat at the Queens Valley is more devastating than flash flooding. Although occurring infrequently, a single episode of torrential rains in the QV watershed, such as happened in November 1994, produces runoff of the magnitude of tens of thousands of cubic meters and transports tons of mud and rock debris from the slopes into unprotected tombs impacting ancient features and site infrastructure. The future will bring more floods. When such floods occur cannot be known, but the ancient monuments can and must be protected in preparation for inevitable flood events.

The aim of this assessment is to provide an informed basis for planning for protecting tombs, historic site elements, and modern infrastructure from flash flood. Factors to be considered are:

- •precipitation records and characteristics of the area;
- •evidence and records of past flooding at QV and on the West Bank;
- •site topography, including the rainfall catchment area, subcatchments, and their drainage characteristics; in this relation, one must also consider changes to the site's topography over time as a result of archaeological investigations, as well as existing and planned infrastructure and previous site interventions intended to afford flood protection;
- •site geology and petrology and susceptibility of the rock to damage as a result of floods;
- •the location of individual tombs and their flood risk before and after protective measures have been implemented.

During the assessment phase of the QV project, these factors were considered with the aim of determining the magnitude and extent of flash flood risk. After the assessment phase, the intent is to apply this information in the design of interventions and management recommendations to protect both historic and modern structures.



Aerial view of the Valley of the Queens showing cultural boundaries and rainfall catchment area that threatens the cultural resources

Key findings

The following are key findings that were determined through the flood protection assessment:

• Flash flood is the greatest threat to preservation of tombs and other historic features.

• Periodic flash flooding of QV is inevitable.

• In the past flood water and sediment have repeatedly flowed into tombs resulting in extensive and immediate damage.

• The clay-rich rock into which tombs are constructed (comprised of marls and shales) swells when wetted, resulting in severe rock damage and, in cases, collapse. The shaley rock of tombs on the south side of the main wadi is particularly susceptible to such impacts, although marls are susceptible to such deterioration as well (as evidenced by QV 60).

• In decorated tombs, mobilization of salts by water leads to salt crystallization in plasters and on wall paintings and extensive damage over time.

• Flooded tombs act as sumps for migration of water through rock fissures to nearby tombs. Therefore, protection of the openings of decorated tombs is not sufficient for their protection. They are also at risk from the flooding of shaft tombs.

• The combined rainfall catchment coverage at the south end of the site parking area is 104 hectares. Five major subcatchments contribute runoff to this confluence point.

• The most dangerous subcatchment to the main concentration of tombs flows through the Cascade at the head of the Valley and into the main drainage channel. This subcatchment has a substantial area (approximately 20 hectares or 50 acres) and a very steep grade (about 30 percent).

• Restrictions to the flow of water and sediment occur near QV 55, at the bridge to QV 66, and at the site entrance.

• Without comprehensive control measures, future floods will result in back-up of water, mud and rock at these areas. Damage to tombs and entrance infrastructure will be severe.

In the pages that follow these findings are elaborated upon, with the aim of identifying specific, significant problems or constraints that should be addressed. The explanation of these issues is followed by proposed measures for their remedy.

History and evidence of flash flooding in the Queens Valley and on the West Bank

The earliest records of rain events in the Queens Valley, rock engravings in the Grotto Cascade, date to the 19th Dynasty of the New Kingdom. These inscriptions record rain during the reigns of Rameses II, Merenptah, and during the late 20th Dynasty (either Ramesses IV, V, or VI) (Penden 2001, 178, 225).

Since the end of the eighteenth century, there have been several written accounts of substantial rain events or flash floods in the Luxor area and on the West Bank, particularly in Kings Valley. These accounts provide an indication of the frequency of substantial storms in the area over the past two centuries. The dates of the most significant events recorded with any specificity are:

Date	Source
1799, 1818, 1820s, 1883, 1898, 1905 , 1910	Cross 2008, 305, n. 7
1914 - March	Romer 1981
1915	Cross 2008, 305, n. 7
1916 - July	Winlock 1948, 8
1916 ,1917, 1918 - October	Cross 2008, 305, n. 7

Date	Source
1949, 1979 - May 3	Romer 1993, 152, n. 22
1975, 1976, 1980, 1989, 1991, 1993	Weeks 1995, 125
1994 - October 8	Brock 1996, 2
1994 - November 3-4	Leblanc 1995, 214
1995 - May 26	Leblanc 1995, 214

Looking again specifically at the Queens Valley, records of early explorers and, later, archaeologists mention sediment in several QV tombs before they were cleared, presumably coming from flash flooding. For example, more than one meter of sediment was found in tomb QV 60, including stratigraphic evidence of at least six to seven major flood events (Messein et al., 1994, 480-481). A number of tombs show significant damage from past flooding or moisture infiltration. These range from damage to wall paintings by the moisture-activated growth of salt crystals, to the loss of painted plasters at the base of walls from flooding and ingress of moisture-saturated debris, to severe structural damage and collapse, particularly within tombs cut into high-clay content shale, and to a lesser extent marl.

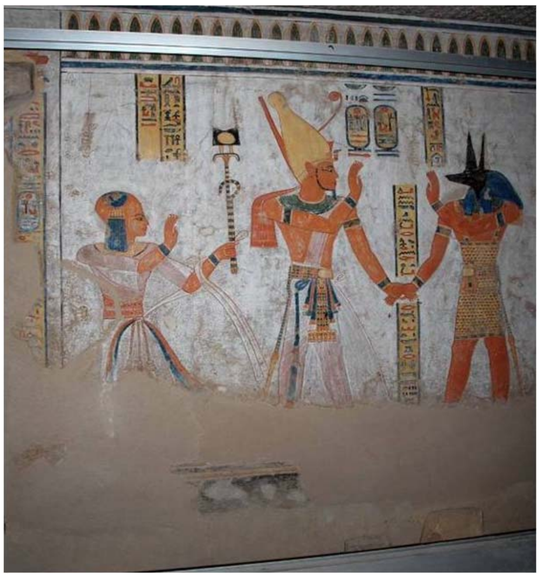
The Franco-Egyptian mission left intact a section of historic alluvial stratigraphy in the wadi's southwest branch to provide a tangible record of historic deposition. Leblanc has noted that this stratigraphic section indicates the occurrence of twelve major depositional events (C. Leblanc, 2007, pers. comm.). C. Leblanc's brief published descriptions of the November 1994 flash flood and another storm in May 1995 are given in the following pages.

Section of alluvial stratigraphy left intact by the Franco-Egyptian mission.

View of Valley at the time of Schiaparelli's mission, looking west from near QV 66 (Nefertari), showing build-up of flood debris. (Image: Schiaparelli 1923)

Between 2006 and 2008 the present assessment systematically recorded physical evidence of apparent flooding and water infiltration in tombs. This included characteristic types of flood-related deterioration that occurred over millennia. It also included recording characteristically cracked clay and silt deposits on tomb floors and adhering to tomb walls, ceilings, and shafts. This latter evidence in most cases presumably indicates flooding or water infiltration since the time of the clearing of these tombs between 1984 and 1988 by the Franco Egyptian mission.

The map on the next page specifies the tombs where flooding was observed in November 1994, or in which flood or infiltration evidence has been found. Table 5 at the end of this section compiles more detailed information concerning each of these types of evidence of flood or water infiltration.

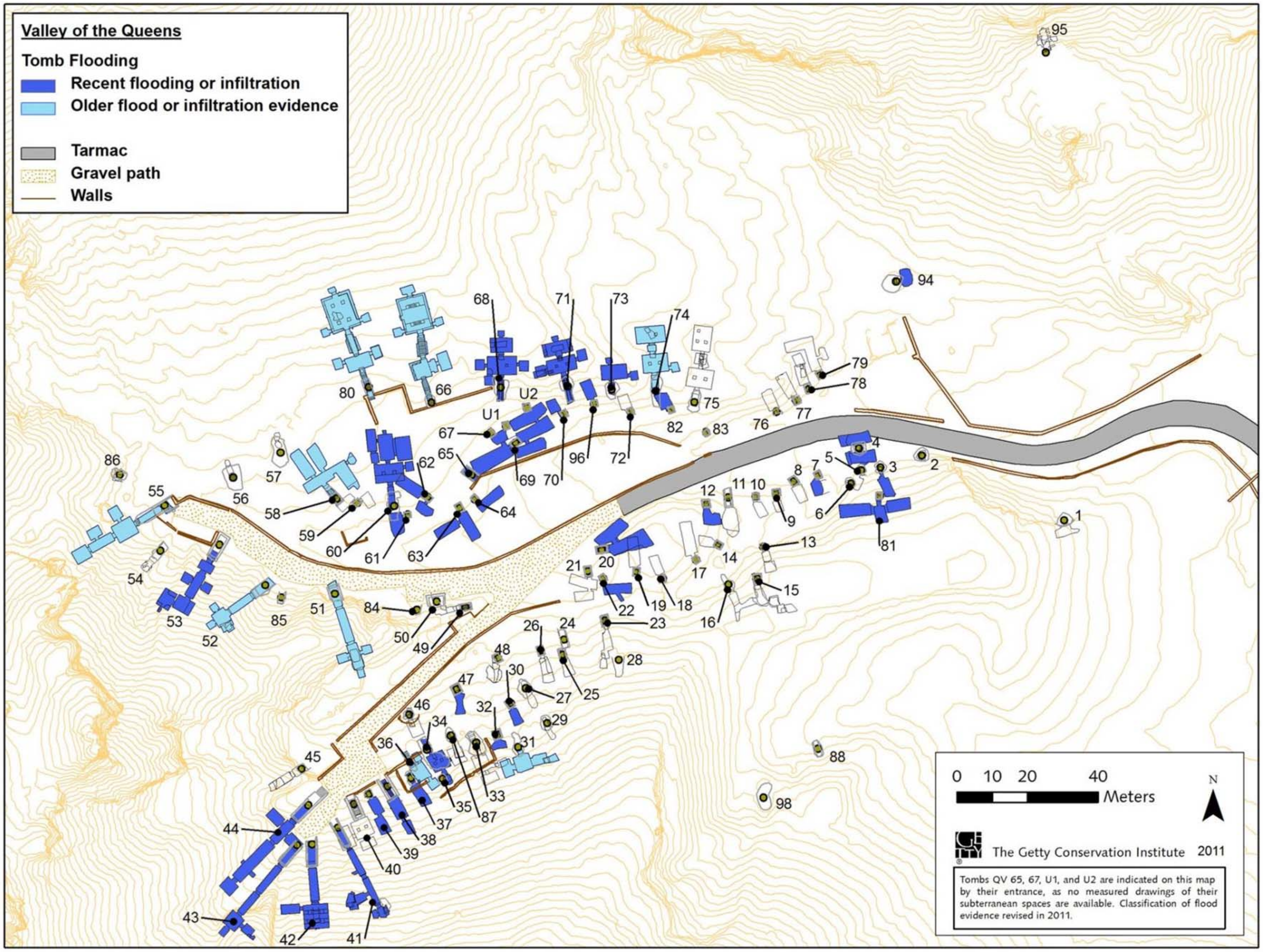


Loss of painted plaster at the wall base of tomb QV 44 (Khaemwaset), presumably due to historic flooding. The tomb is open to general visitation.

Loss of painted plaster at the wall base of tomb QV 52 (Tyti) presumably due to historic flooding. The tomb, open to general visitation, is in a vulnerable position near the main drainage channel.

Rock collapse, deterioration, and loss of painted plaster in the lower walls of tomb QV 60 (Nebettauy) due to repeated flooding, including in 1994.

View of roof collapse of tomb QV 34, which is in an area where most tombs contain shale susceptible to water damage.



Tombs with recent flood or infiltration evidence (since 1980s), or in which older flood or infiltration evidence (prior to the 1980s) has been found. Evidence is specified in Table 5.

1994 flash flood

The largest flood in the Valley of the Queens in recent times was on 2 November 1994. This is also the only instance of flooding at the site for which detailed direct observations have been recorded. Leblanc indicates that rain lasted for approximately one hour. The Luxor airport meteorological station recorded 1.02mm of rain on November 2 and 0.51mm on November 3. As already noted, from written and oral accounts of flooding on the West Bank, the amount of rainfall there was substantially more than at the airport.

Leblanc wrote the following regarding the situation in the Valley of the Queens during that episode:

> The clearing of the bottom of the necropolis which had been done between 1986 and 1990, thanks to the Ford-de-Maria donation, allowed the restoration of a portion of the ancient topography of the site but the work had not been pursued beyond the tombs [QV 49]-[QV 50] because of the presence of the asphalted parking [in the main wadi]. When the rain fell, the water, instead of continuing its own path, had been blocked by this modern pavement raised multiple times and which formed an artificial dike. As soon as the section of the ancient bed which had been cleared by the CNRS and CEDAE team was full, the overflow poured into the tombs located on the side. (Leblanc 1995, p. 213; translation from the French by GCI)

The flow of the floodwaters was further impeded by a raised footpath that followed north from the current parking area in the heart of the wadi to the tomb of Nefertari, which acted like a dam but broke from the force of the floodwaters. Thirty-two tombs have been identified that were presumably flooded during that episode (indicated in the preceding map). No record exists of the amount of rainfall that fell in QV during the 1994 flood.

Water standing in the wadi after the 1994 flood. QV 55, one of the three tombs open to general visitation, is indicated by arrow. In the foreground are the foundations of Rameside-era and Coptic-era structures and tomb QV 58, now a magazine, on the right. (Image: CNRS)

Response to the1994 flash flood

Immediately following the November 1994 flood, CNRS and SCA intervened to protect the Queens Valley tombs. The first action taken was pumping of water and removal of mud from flooded tombs. Leblanc has recounted that during the pumping of water from certain shaft tombs rock could be heard collapsing as a consequence of swelling due to the clay content of the marl (C. Leblanc, 2009, per. comm.). Following these actions, CNRS and SCA worked for approximately two weeks to improve the situation in the valley (C. Leblanc 1995, p. 213). This work included removing the asphalt road and parking area in the heart of the valley (opposite QV 66) and lowering the level of the Valley floor, in some areas up to one meter and to bedrock, to further reduce the threat of flooding. The parking area was removed to also eliminate vibrations caused by vehicles, particularly tour buses. The work was carried out using heavy equipment of the SCA's architectural department.

A path from the site entrance was built on the south side of the main wadi to the former parking area. The remains of the existing footpath between the former parking area and Nefertari's tomb were also removed to free the main drainage path in the wadi. In its place a new path for tourists to access Nefertari's tomb was created by installing a small wooden footbridge across the wadi and from there utilizing a terrace in front of the tombs of Ramses II's daughter-wives (QV 70, QV 72, QV 75, QV 82, QV 83).

The CNRS and SCA also replaced existing low walls around a number of tombs with new, higher stone walls with the intention of diverting flood waters. This work included walls around the entrances to QV 41, QV 42, QV 43, QV 44, and walls built around the four sides of the opening to QV 65. A low protection wall was also built next to the path in front of QV 55. In the southwest branch of the main wadi existing low walls along the visitor path were replaced with rough stone walls to better channel water in the direction of the main wadi.

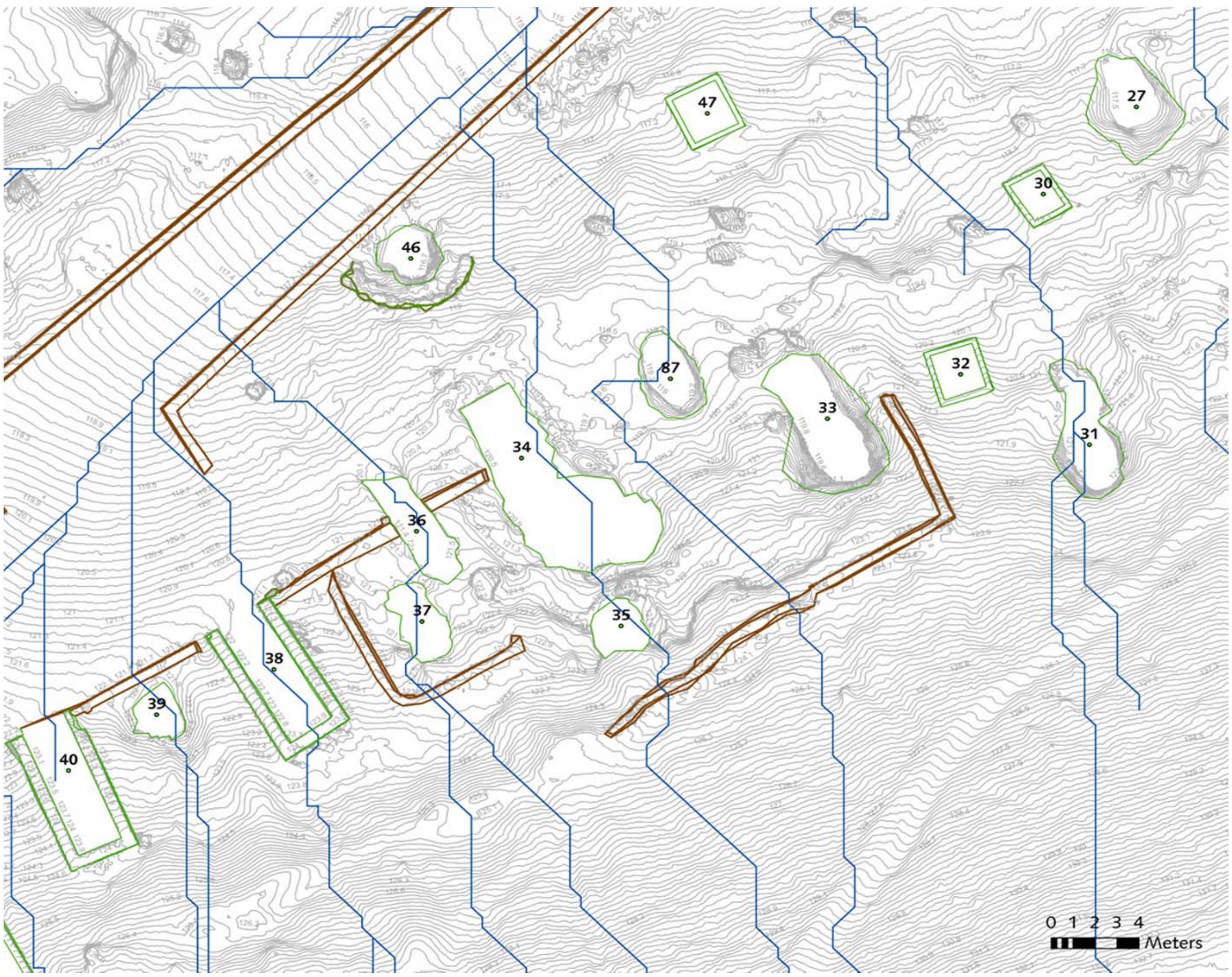
Leblanc has stated, regarding the effectiveness of these interventions, that '[t]he heavy rain which fell on 26 May 1995 showed that all of these installations have been very efficient, since no infiltrations, this time, penetrated the tombs of the necropolis' (Leblanc 1995, p. 214; translation from the French by GCI). However, Leblanc has since warned that the Valley's shaft tombs still need protection (C. Leblanc, 2007, pers. comm.). Although these measures substantially improved the situation, the present assessment has identified several significant deficiencies that remain.

The former parking area was removed after the flood (Image: CNRS).

Workmen pumping water from the main wadi immediately after the 1994 flood. The former parking area, which blocked the flow of flood water and debris, is indicated by the arrow (Image: CNRS).

New site mapping

The topographic characteristics of a rainfall catchment determine the hydraulic behavior of runoff during rainfall. As noted elsewhere in this report (see Part II: Appendix 2), in 2007 the GCI commissioned a new topographic map of the site to include the locations of the tombs, other ancient features, and modern infrastructure. Before this new mapping, the most precise map covering the majority of the QV catchment area had been produced by the French Institut Geographique National in the mid 1960s with a topographic contour interval of 2 meters. Importantly, this map predated the 1994 changes to the topography in the heart of the main wadi, which included removal of both the asphalt parking area and the built up path that connected it to the tomb of Nefertari, and the creation of a drainage channel and terraces in the area and construction of a new asphalt parking area at its current location at the site entrance. The 2007 GCI mapping utilized long-range and short-range laser scanning instruments and other survey equipment to produce an accurate and detailed map with a 50cm contour interval covering the entire rainfall catchment area, and with a 10cm contour interval in the area of the main concentration of tombs.



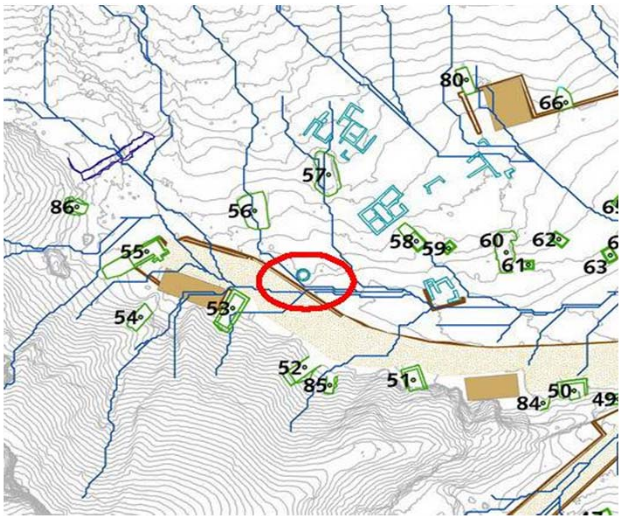
Part of the topographic map produced through laser scanning of an area of the southwest branch of the main wadi showing 10cm contour lines (gray), tomb openings (green lines), and drainage lines (blue) generated through ArcHydro 2.1 hydrologic analysis software. Software generated drainage lines suffice to show an approximate picture of flow, but require correction in some instances by in situ inspection, particularly around tombs.

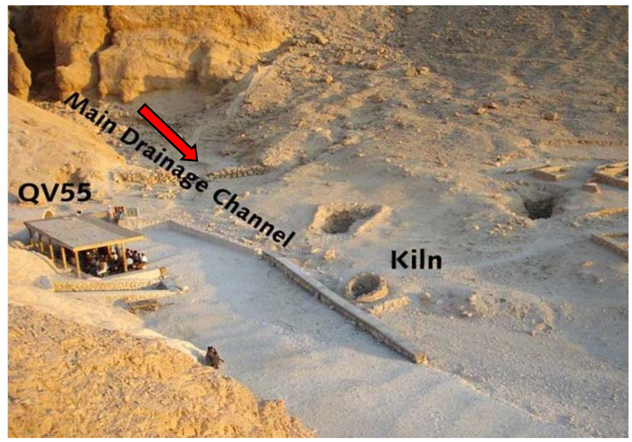
Identification of key areas of concern

Through on-site assessment, a number of key issues were identified that require attention in order to protect the Valley's antiquities and infrastructure from flood.

Issue 1: Obstruction of channel by ancient Kiln

The ancient Roman or Coptic kiln is in the path of the main drainage flow near tombs QV 55 and 53. The direction of flow is indicated on the map and image by arrows. A wall was constructed in 2007 along the north side of the visitor path next to the kiln, which almost completely constricts the channel on the kiln's south side.

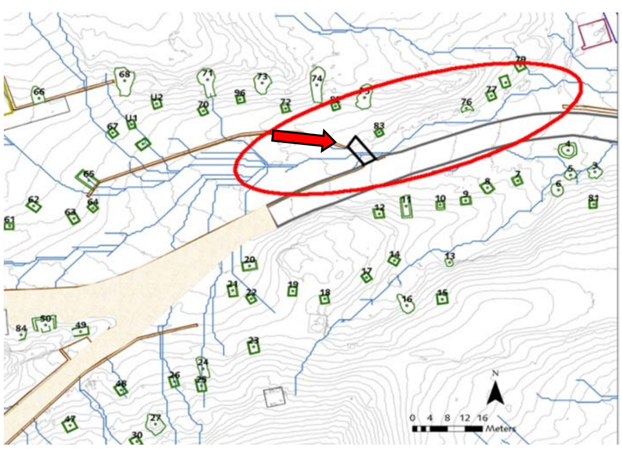




Location where the kiln obstructs the main drainage channel.

Issue 2: Constraint of main drainage channel

At present the main drainage channel increasingly narrows toward its east (downstream) end. The elevated asphalt visitor path downstream of the bridge to QV 66 reduces the flood channel from its original more than 10 meter width to less than 2 meters. This narrowing and the bridge create a severe obstruction to the flow of water and debris. The depth of the entire channel has also decreased over time as debris has accumulated in it. Many significant tombs and other historic site elements densely situated close to the channel are at risk if the channel fills or overflows either because its capacity is exceeded or it becomes blocked and backed up.

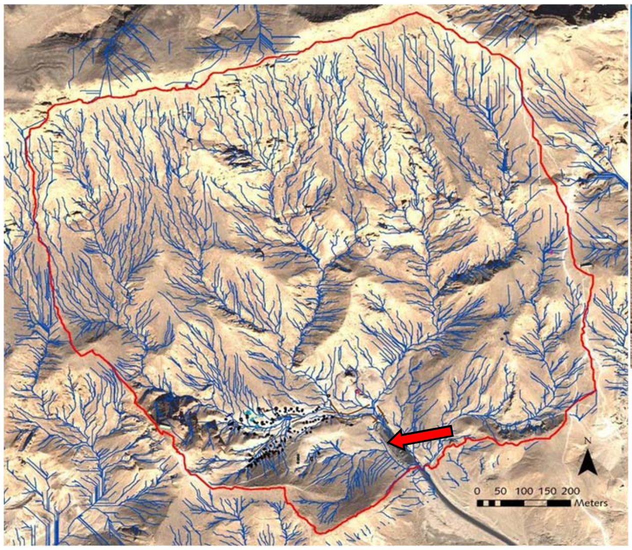


Map of area of constriction of main drainage channel by bridge (indicated by arrow) and paved visitor path.

View of main drainage channel looking downstream showing channel narrowing and point of constriction at bridge (arrow).

Issue 3: Convergence of subcatchments at site entrance

The convergence of flows from the six main sub-catchments threatens infrastructure at the site entrance. Blockage at this point would result in back-up of water, mud and rock and affect the entire site.



Above: View of the convergence of drainage subcatchments at the site entrance.

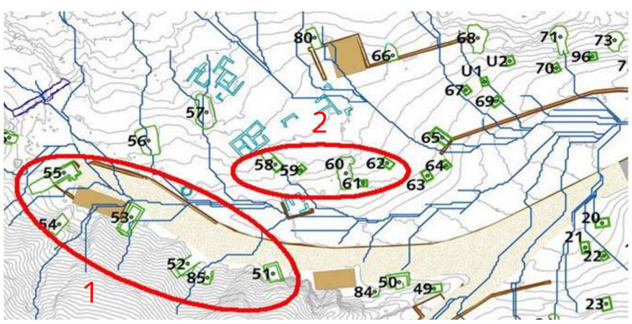
Left: Drainage lines for entire catchment (104 hectares) with their convergence at the site entrance (indicated by arrow). (Satellite image: 2006 DigitalGlobe).

Issue 4: Threat to tombs from main drainage channel

Tombs are immediately threatened by overflow of the main drainage channel in two areas that will be fed by a catchment exceeding 22 hectares:

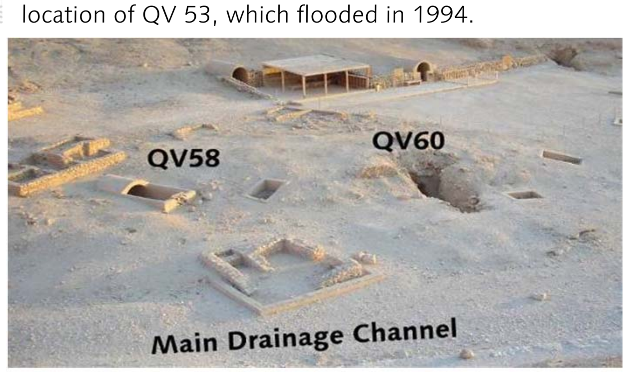
• <u>Area 1</u>: Two of the tombs open to general visitation, QV 52 and QV 55, and other significant tombs (e.g. QV 53 flooded in 1994) are in a vulnerable position on the south side of the channel.

• <u>Area 2</u>: Tombs QV 58, 59, 60 and 61 on the north side of the channel are under threat from flow through the main channel. QV 58 is a magazine used to store archaeological materials and QV 60 has been affected by repeated flooding including in 1994.



Left: Map of tombs in Areas 1 and 2 vulnerable to flooding from the main drainage channel.

Below: View of Area 1 (left) and Area 2 (right). Note location of QV 53, which flooded in 1994.



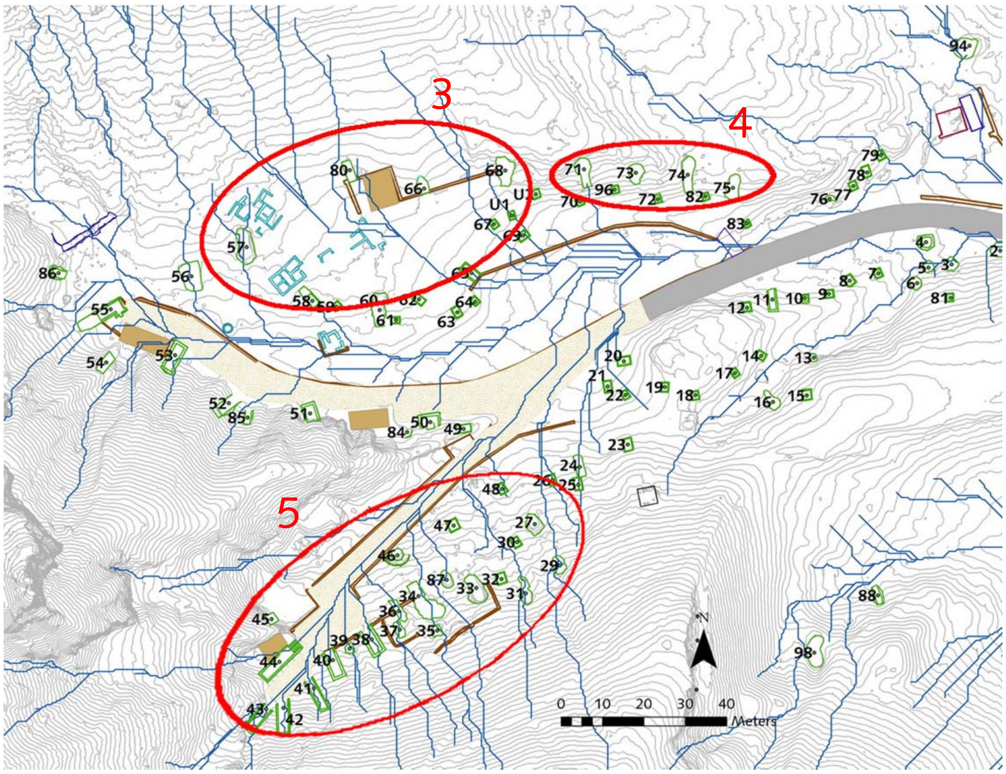
Issue 5: Threat to tombs from upslope runoff

Tombs are threatened by upslope runoff in three general areas that require area-wide control:

Area 3: QV 58 –66 and tomb workers' structures;

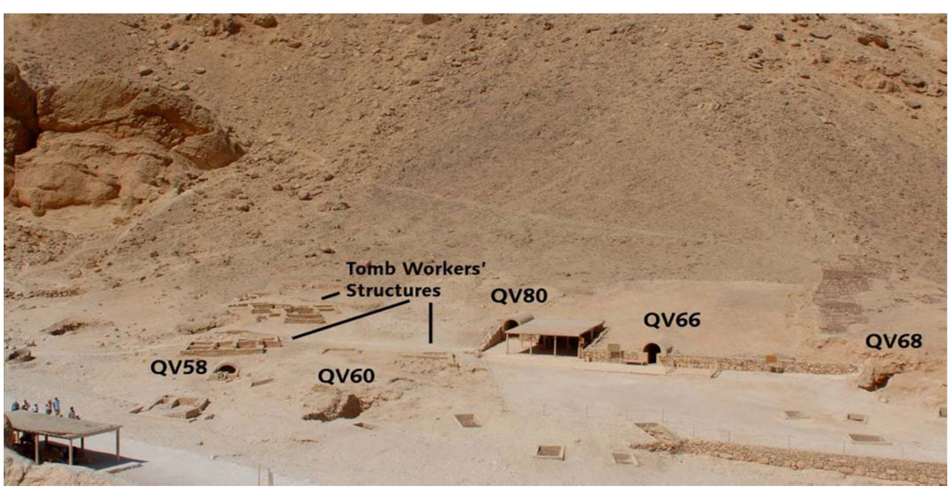
Area 4: QV 71 – 75;

Area 5: QV 27 – 44, 46 – 48.



Area 3 : QV 58 – 66 and tomb workers' structures

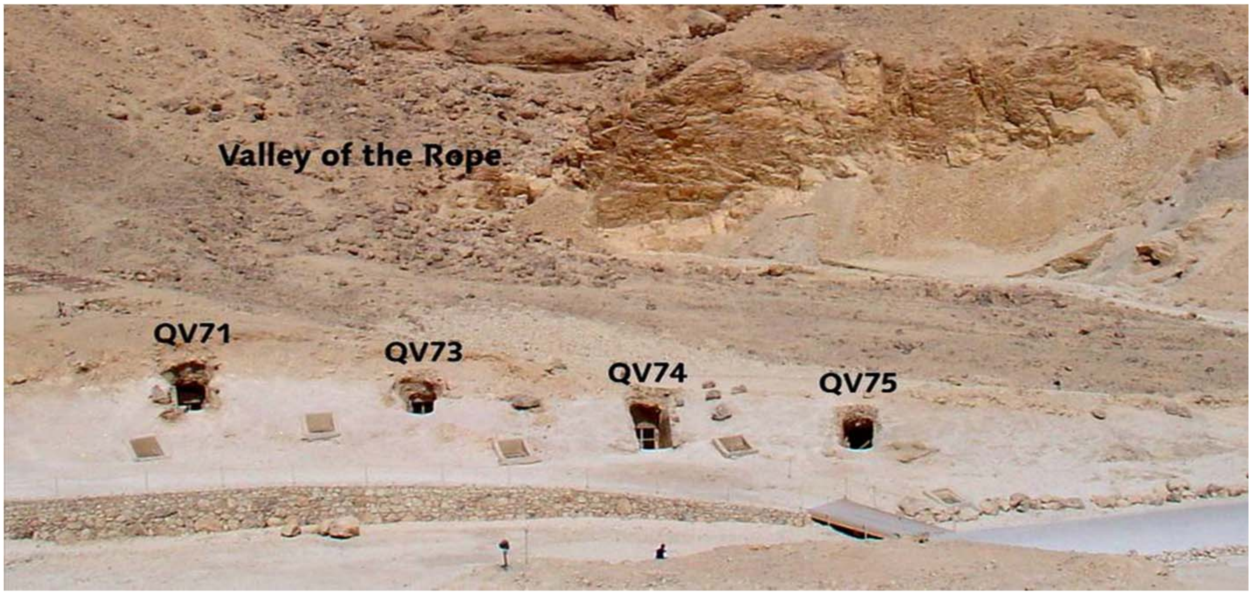
Tombs QV 58 – 68 include QV 66 (Nefertari) and QV 68 (Queen Merytamen). Tombs QV 58, 60, and 68 flooded in 1994. Hydrologic analysis shows substantial runoff down slope through the western part of this area.



General view of Area 3 tombs and features that are vulnerable to runoff from the slope above.

Area 4: QV 71 – 75

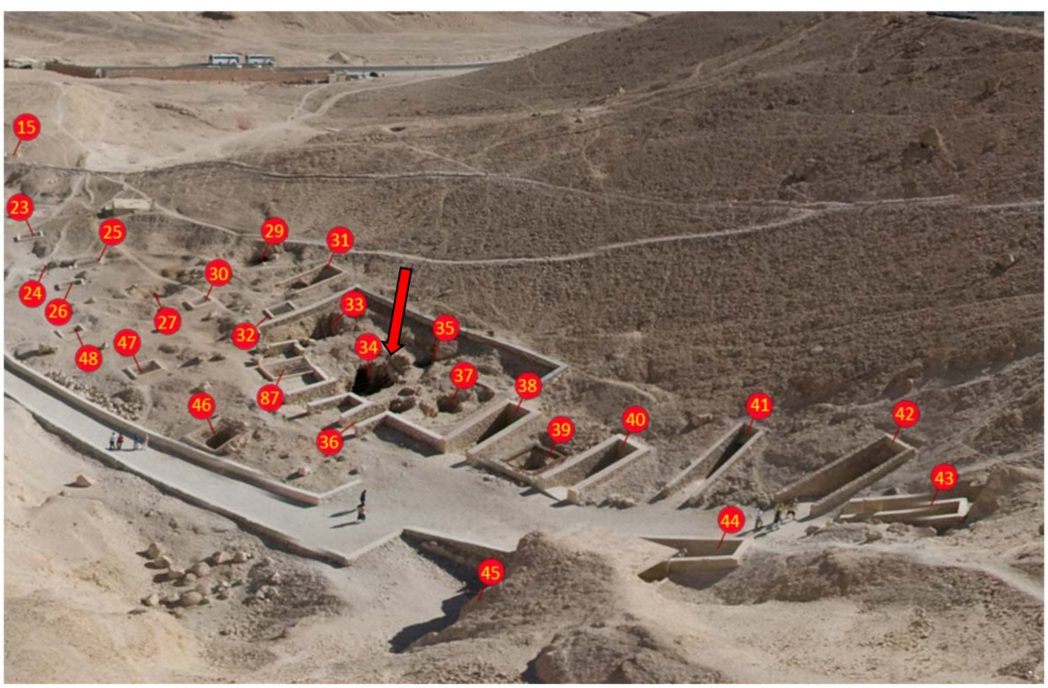
If a substantial flood event occurs, tombs QV 71 – 75 are vulnerable from upslope overflow from the Valley of the Rope drainage path to the north. The chief of the SCA site guardians indicated that QV 71 and 73 flooded in 1994 (2009 pers. comm.).



General view of Area 4 showing the Valley of the Rope outflow in the background.

Area 5: QV 27 – 44, 46 – 48

Many of the tombs in Area 5 contain expansive shale and in some areas this rock is exposed at the ground surface. This area also includes the collapsed roof of QV 34, which is highly susceptible to water infiltration and further damage. The SCA built a wall around this unstable area in 2009.



General view of Area 5, with arrow indicating QV 34 with collapsed roof.

Hydrologic analysis and hydraulic modeling

After the GCI carried out an in-depth field assessment, GCI consultant Hamza Associates conducted hydrologic analysis and hydraulic modeling to assess the magnitude and extent of the flash flood threat under the existing conditions. The following were the steps carried out in this process:

Hydrologic Analysis

1. Rainfall analysis of the study area
2. Sub-catchment delineation
3. Rainfall-runoff analysis to determine the expected peak discharge and flow volume corresponding to a 200 year return period
4. Analysis of sediment yield from the catchments

Hydraulic Modeling

1. Simulation of the present situation (without the introduction of flood protection measures) and evaluation of flood risk.

A summary of this work follows directly after a discussion of sources of historical rainfall data for the Luxor area.

Sources of rainfall data

Apparently no meteorological station has been established on the West Bank and thus, after several years of searching exhaustively, it appears that rainfall records do not exist. A station on the West Bank is needed to accurately determine the entire Theban necropolis' needs for flash flood protection. However, a meteorological station at the Luxor airport on the East Bank is operated by the Egyptian Meteorological Authority, and rainfall records exist from that station back to the early 1940s. This apparently is the only source of long term rainfall data in the Luxor area. The convectional type of storms that predominate in the area are typically highly localized, with rain falling heavily in one location while a nearby area may be dry. In cases, substantial rain events have occurred on the West Bank when at the same time little or no rain was recorded at Luxor airport. For example, at the time of the November 1994 flash flood on the West Bank little rainfall was recorded at the airport.

In addition, the topographic position of the airport is relatively flat and low lying (elevation 93 meters) with no nearby mountains. In contrast, the Queens Valley watershed, approximately 12 kilometers to the northwest, includes the south-facing slope of the Theban Mountain with elevations at its top exceeding 460 meters. When moisture-containing air masses are forced higher as they rise up the Theban Mountain in the Queens Valley watershed, the resulting adiabatic cooling can be expected to lead to more intense rainfall than occurs in the lower, flatter area of Luxor airport.

Rain storms in the area of Thebes in recent times also have tended to have a distinct seasonality. K. Weeks states that "virtually all of the recent heavy storms at Thebes in the 20th century (or at least those for which we have records) occurred in the months of October, November, or early December" (Weeks 1995, p. 125).

These factors together mean that precipitation records from the airport meteorological station may not be an accurate indicator of the frequency, and magnitude, of historical rainfall events at the Queens Valley. However, they are the only available local records.

West Bank environmental monitoring has been conducted in two known instances. During the 1990s the GCI maintained an environmental monitoring station at the Queens Valley as part of its project to conserve the wall paintings of the tomb of Nefertari. This station recorded precipitation for the following two periods: (1) January 1991 - September 1993: no precipitation recorded; (2) January 1996 - May 1997: 0.5 mm (Aug 23-24, 1996) and 1.75 mm (Nov 14-15, 1996). Unfortunately, this station was not installed at the time of the 1994 and 1995 storms. K. Weeks notes that a station operated in Kings Valley briefly in 1997-1998 but that its records have not been located (TMP 2006, 59). For the purposes of the current project, the GCI again installed an environmental monitoring station at Queens Valley in late January 2008.

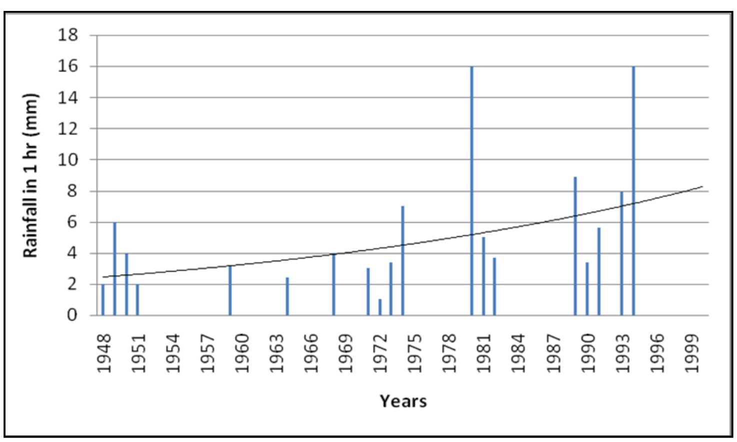
Rainfall analysis

In order to assess the magnitude and extent of risk of flash flooding at Queens Valley, data had to be analyzed for peak rainfall events over a short duration. The analysis that follows was undertaken in conjunction with Dr. Reda El-Damak, Dr. Ashraf Ghanem, and Dr. Mohamad El-Gamal under contract to Hamza Associates (El-Damak, Ghanem, and El-Gamal, 2010). This analysis utilized hourly data from Luxor airport published by K. Weeks showing the occurrence each year between 1940 and 1994 of the storm that "dropped the greatest amount of rainfall – at least 1 mm of rainfall – in a one-hour-long period. … If several storms occurred during a year the graph only records the occurrence that dropped the most precipitation over one hour." (Weeks, 1995, 123).

Table 1

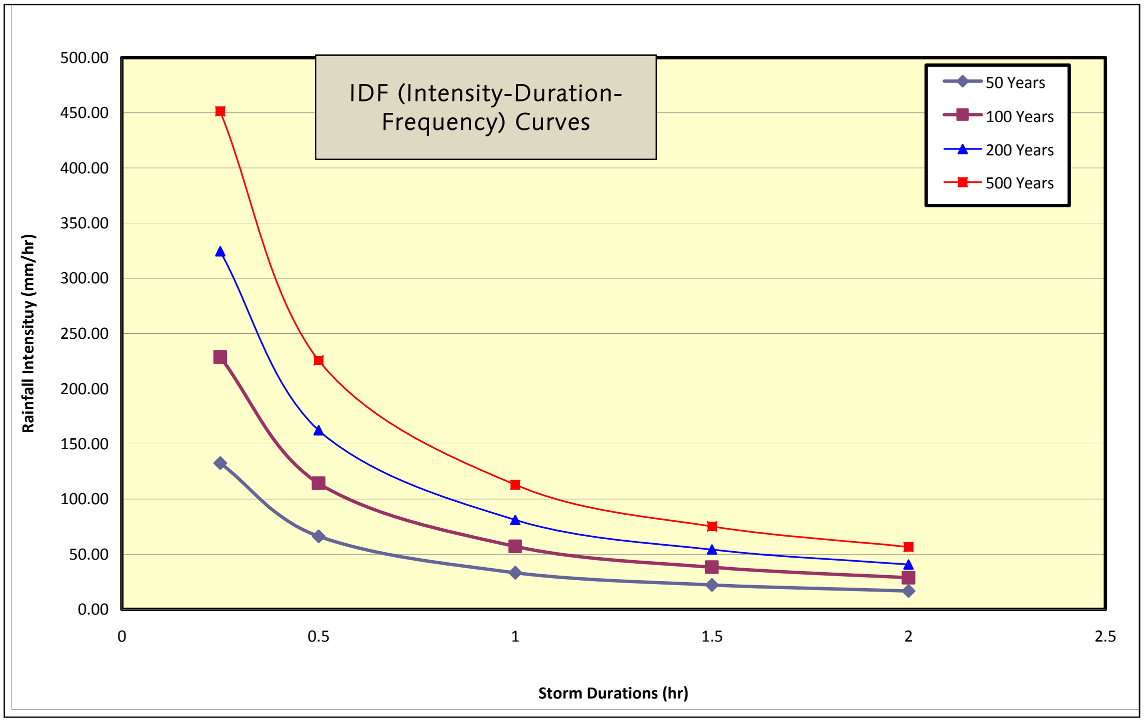
Month	Mean Temperature °C Daily Minimum	Daily Maximum	Mean Total Rainfall (mm)	Mean Number of Rain Days
Jan	5.7	22.9	0.10	0.10
Feb	7.1	25.2	0.10	0.07
Mar	11.0	29.3	0.30	0.10
Apr	16.0	35.0	0.10	0.01
May	20.4	38.9	0.30	0.20
Jun	22.8	41.1	0.00	0.00
Jul	23.9	40.9	0.00	0.00
Aug	23.5	40.6	0.01	0.01
Sep	21.6	38.8	0.30	0.03
Oct	17.8	35.3	1.20	0.30
Nov	12.0	29.4	0.20	0.07
Dec	7.5	24.4	0.04	0.05

Table 1 presents general climatological information for Luxor airport meteorological station compiled from the World Meteorological Organization (WMO) website based on monthly averages for the 30-year period 1971-2000. The mean number of rain days accounts for days with at least 0.01 mm of rain (World Meteorological Organization, http://worldweather.wmo.int/059/c01271f.htm#climate accessed 11 October 2010).



The graph plots storms of one-hour duration with heaviest rainfall by year, 1948-1994, with trend line (revised from Weeks 1995, 123). It shows that the maximum rainfall events took place in 1980 and 1994, with each having a rainfall intensity of 16mm/hr. As Weeks noted, most significant storms seem to come in roughly three- or four-year clusters once every decade or so. In addition, there is a positive increasing trend of the intensity of significant storms (as indicated by the trend line) and there is a greater number of heavy storms in more recent decades than in earlier ones, which might indicate that there is also a longer-term cyclical pattern of storms (Weeks, 1995, 125).

As a next step, a time series analysis was conducted over the period of simulated storms for return periods ranging from 50 to 500 years and storm durations of up to 2 hours. Based on the daily rainfall data recorded at Luxor airport station, the graph below (Intensity-Duration-Frequency curves) shows the extreme value plots of maximum daily rainfall. This plotting confirms that peak storm events in the Luxor area are typically of short duration, and begin with heavy rainfall that rapidly lessens in intensity.



A return period represents the probability of a storm of a given intensity occurring in the future based upon available statistics of past rainfall events. For the return period chosen for Queens Valley (200 years), the probability of a storm of this magnitude occurring in any given year is 1/200 or 0.5%. The rainfall projections produced through the modeling are not a prediction of actual storms in the future, but are solely based on statistical analysis of historical data from Luxor airport and the projection of probabilities into the future based on those statistics. Those probabilities will inevitably change as new rainfall data is collected in the future. As noted before, this data from the East Bank does not accurately reflect past rainfall events on the West Bank.

Table 2
Maximum Daily Rainfall (mm)

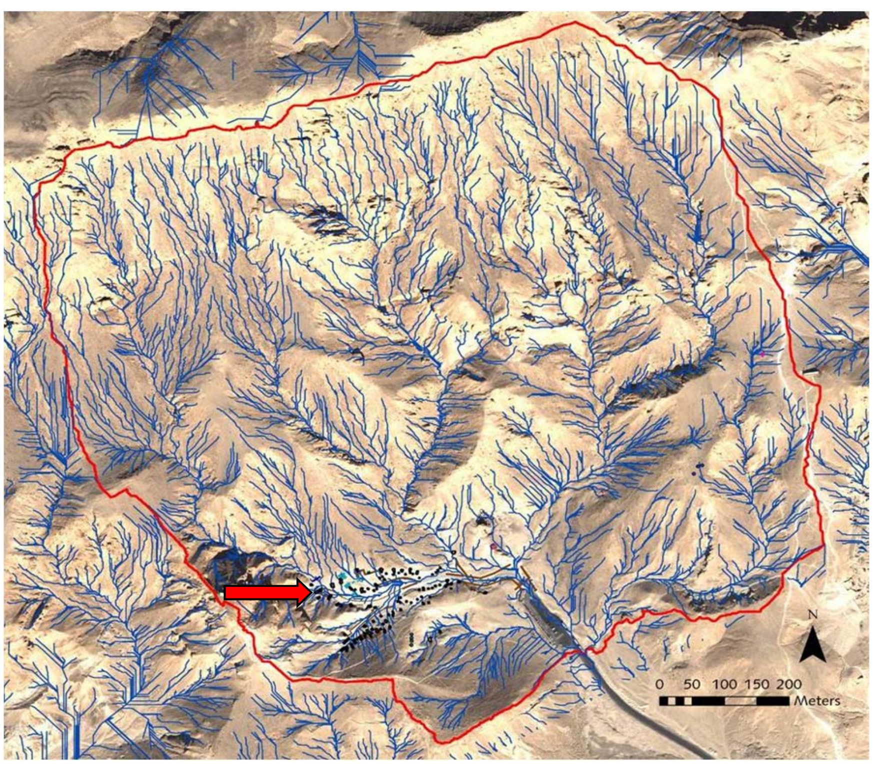
Return Periods (years)	Maximum Daily Rainfall (mm)	Rainfall Intensity (mm/hr) Storm Duration (hr) 0.25	0.50	1.00	1.50	2.00
30	15.45	61.80	30.90	15.45	10.30	7.72
40	25.41	101.64	50.82	25.41	16.94	12.70
50	33.13	132.54	66.27	33.13	22.09	16.57
60	39.45	157.78	78.89	39.45	26.30	19.72
70	44.78	179.13	89.57	44.78	29.86	22.39
80	49.41	197.62	98.81	49.41	32.94	24.70
90	53.48	197.62	98.81	49.41	32.94	24.70
100	57.13	228.52	114.26	57.13	38.09	28.57
200	81.13	324.51	162.26	81.13	54.09	40.56
300	95.16	380.66	190.33	95.16	63.44	47.58
400	105.12	420.50	210.25	105.12	70.08	52.56
500	112.85	451.40	225.70	112.85	75.23	56.42

Table 2 presents the maximum rainfall data for return periods ranging from 30 years to 500 years and storms lasting from one-quarter hour to two hours. The projected maximum rainfall for the modeled storm (200 year return period, one hour duration) is 81 mm.

Rainfall runoff modeling and sediment analysis

The Watershed Modeling System (WMS), a leading software package for graphical watershed computer simulations, was used for hydrologic modeling to delineate the rainfall catchment area and to analyze rainfall runoff. The new topographic mapping data was imported into the WMS package to develop a Digital Elevation Model (DEM) of the QV catchment area. Within WMS, the DEM was used to automatically delineate the overall catchment and sub-catchment boundaries, identify flow lines, as well as calculate flood hydrographs and water volumes for different sub-catchments. This analysis concluded by estimating sediment yields for peak rainfall events.

The QV rainfall catchment area, which extends to the top of the Theban Mountain, covers 104 hectares (more than 1 km square). The concentration of tombs at the base of the mountain is indicated by the arrow.



Satellite view of the QV rainfall catchment area with superimposition of drainage lines generated through ArcHydro software from new topographic mapping. The arrow indicates the area of tomb concentration. All runoff converges at the entrance to the site and parking area, creating high risk for the tombs and site infrastructure. (Satellite image: 2006 DigitalGlobe).

The analysis using WMS software confirmed that the total QV rainfall catchment area is about 1.04 km² (104 hectares). This modeling divided the QV catchment into five major sub-catchments, as shown in the figure below. The characteristics of each major sub-catchment are contained in Table 3 that follows. The analysis also identified two other minor sub-catchments, each with areas of approximately 0.02 km², that are not included in the table. These minor sub-catchments, labeled 6 and 7 on the map below, include what is referred to in this report as the southwest branch of the QV main wadi (identified as no. 6). The background color of the figure below indicates relative elevation above sea level of the QV topography, with orange and red indicating the lowest elevations and green and blue indicating the highest.

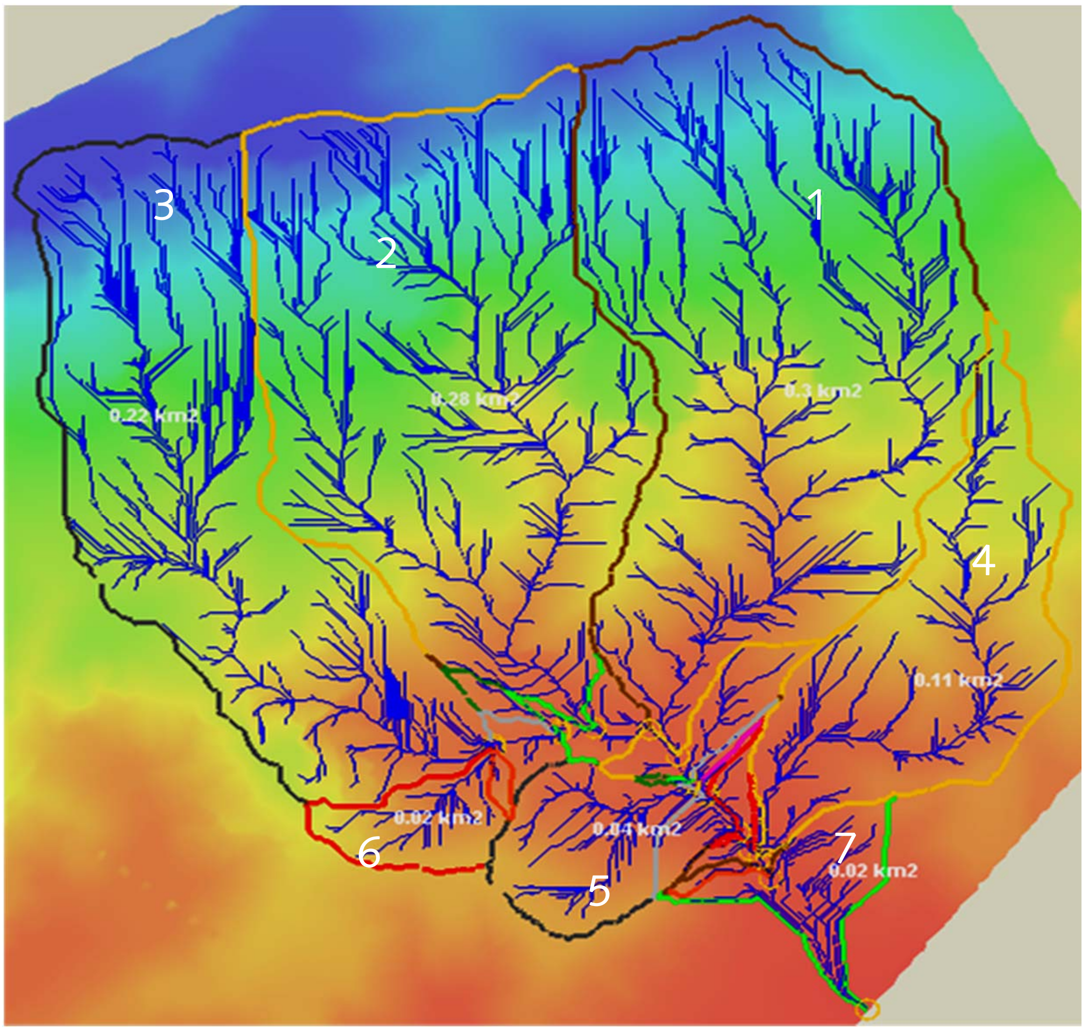


Table 3. Characteristics of Queens Valley Major Rainfall Sub-Catchments					
Sub-catchment No.	1	2	3	4	5
Common Name	Valley of the Three Pits	Valley of the Rope	Valley of the Grand Cascade	Valley of the Dolmen	Valley of Prince Ahmose
Area (km²)	0.30	0.28	0.22	0.11	0.04
Length (m)	1228.7	1036.3	1151.0	955.4	312.4
Maximum Stream Slope (m/m)	0.27	0.35	0.30	0.15	0.16
Average Elevation (amsl)	250	266	264	150	124
Sinuosity (msl/l)	1.28	1.18	1.25	1.27	1.15

Land cover and rainfall runoff

The watershed modeling also necessarily took into account the type of land cover, which greatly determines the runoff to rainfall ratio. First, it should be noted that the catchment area is in a desert environment with essentially no vegetative cover to retain water runoff. Based on surface sampling in various parts of the catchment area by Hamza Associates, it was noted that the Queens Valley land cover consists of sedimentary rocks that comprise the highlands, with sedimentary soil, gravel, and boulders on the surface of the slopes to the wadis. It was further determined that the catchment has generally low infiltration rates due to the composition of the ground surface and absence of vegetation. Accordingly, a high runoff coefficient is expected resulting in flash floods.

Based on land cover characteristics, particularly soil type, a quantitative estimation of water runoff was calculated to derive a runoff curve number (also called a curve number or simply CN). The CN is an empirical parameter used in hydrology for predicting direct runoff or infiltration. The CN is widely used as an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based specifically on an area's hydrologic soil group, land use, treatment and hydrologic condition. CN has a range from 30 to 100; smaller numbers indicate low runoff potential while larger numbers are for increasing runoff potential. Based on the characterization of Queens Valley land cover conditions, the CN of the catchment area is expected to range from 80 to 85. However a more conservative value of CN=90 was used in this study.

HEC-HMS model and peak runoff flow

The HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) software package was used to calculate the runoff flow hydrograph for each sub-catchment in addition to the routed total hydrograph at the outlet point at the south end of the QV parking area. The generated sub-catchment data were exported from the WMS package to the HEC-HMS package. Peak flow data was calculated for a 200 year return period storm event and for a CN value of 90. The projected total peak runoff flow at the wadi outlet at the south end of the QV parking area is approximately 17 m^3/s.

Estimated sediment yield

As noted previously, a flash flood at Queens Valley will not only produce rainfall runoff, but a flow of water mixed with mud and rock debris. This has been evidenced by the substantial amounts of flood-carried sediment found in many of the QV tombs when they were cleared through archaeological investigation. Therefore, the flash flood assessment is needed to also calculate the expected sediment yield of the modeled storm event. Sediment yield is a hydrologic term for the volume of sediment passing a cross-section during a specified period of time, and may be estimated for a single rainfall event. Several different equations are typically used to estimate sediment yield and their results can vary significantly. Therefore, the QV hydrologic analysis utilized the following four such formulas:

- Laursen (1958);
- Yalin (1963);
- Yang (1974);
- James Rankl (2004).

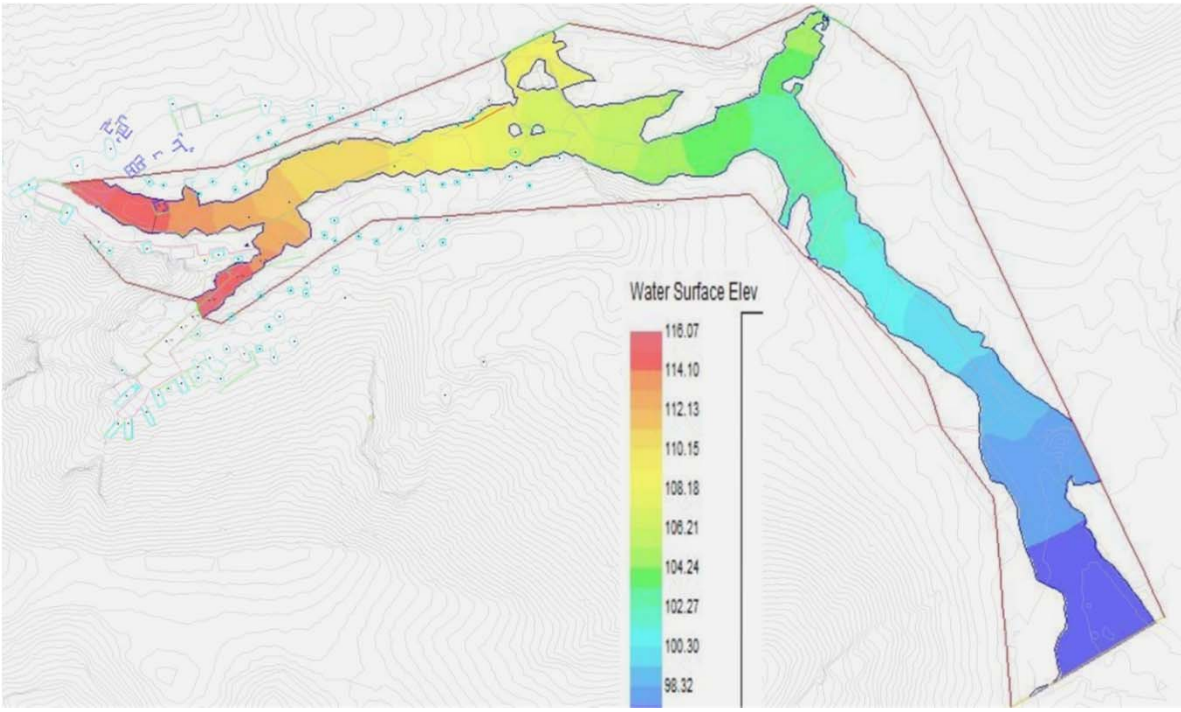
The values produced by each of these four formulas were then averaged to derive an expected sediment yield projection for the modeled storm event (200 year). These are shown in Table 4.

Table 4. Average Sediment Yield Calculations										
Q_{200} (m^3/s)	0.25	0.5	1	3	5	7	9	11	13	15	17
Sediment (m^3)	61	128	266	864	1494	2145	2813	3498	4193	4898	5614

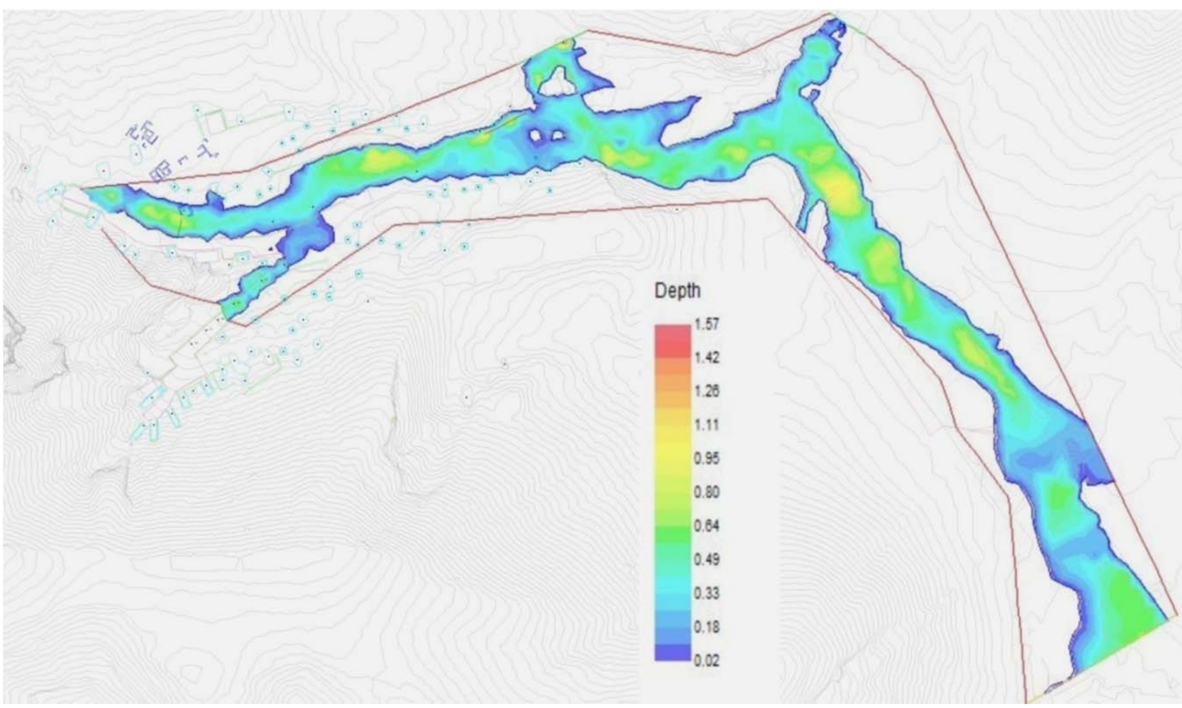
At the wadi outlet at the south end of the parking area, the peak rainfall runoff flow (Q_{200}), as noted previously, was calculated to be approximately 17 m^3/s. For peak flow of this magnitude, the projected total sediment yield is 5,614 m^3 (highlighted in yellow).

Hydraulic modeling of flood risk under present conditions

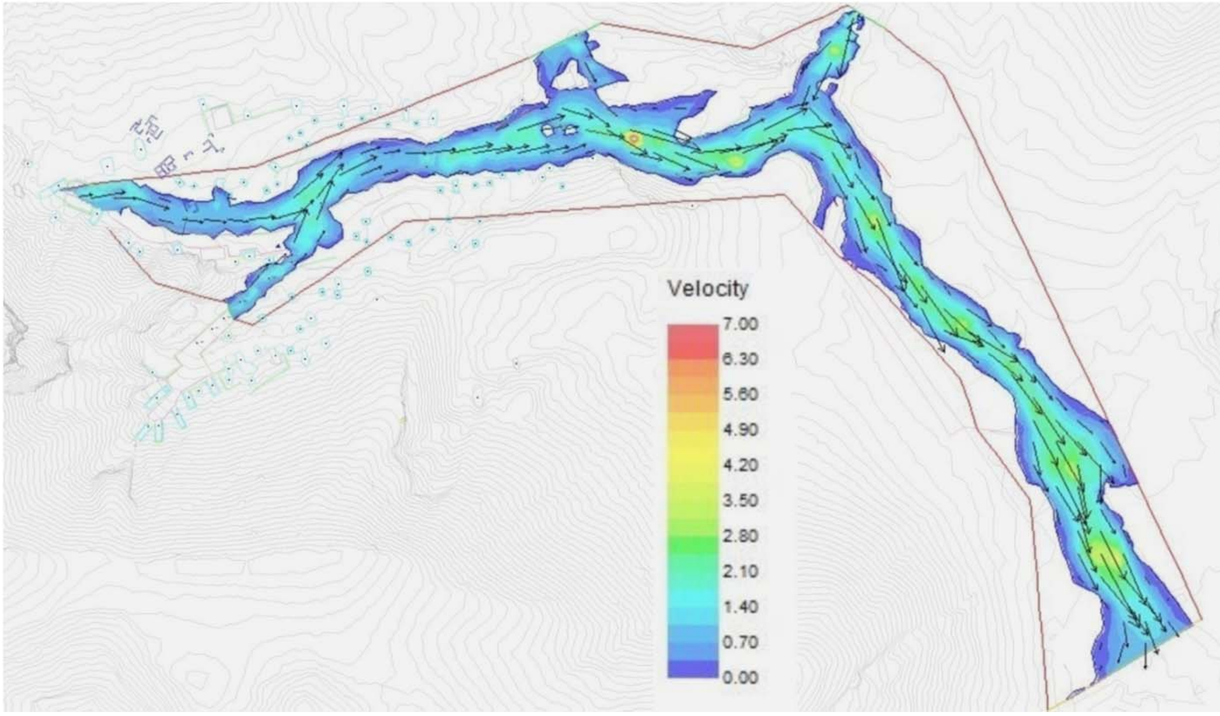
Hydraulic modeling was carried out based on peak discharge values obtained from the previously discussed hydrologic modeling. Hydraulic simulation of the peak flows from the main sub-catchments running through the main wadi channel was used to assess the capacity of the channel to carry such flows and therefore identify areas of flood risk. The following three graphics show computed water surface elevations, depth, and velocities, respectively, for the 1 in 200 year flood event.



Computed water surface elevations (meters above mean sea level) based on a 200 year flood under the present situation.



Computed depth values (meters) based on a 200 year flood under the present situation.



Computed velocity values (meters/sec) based on a 200 year flood under the present situation. Arrows are velocity vectors, which indicate the local direction of flow and the length of the arrow is proportional to the velocity at that location.

The following are significant points from the graphical results of the modeling in the area of the main wadi:

- tomb openings shown with water over them or very close to them are: QV 2, 3, 4, 7, 8, 49, 60, 61, 76, 77, 78, 79, 83, and 94.

- historic site elements shown being impacted by flood water are the Kiln and Structure II of the Coptic remains located near the main drainage channel between tombs QV 51 and 69.

- modern infrastructure shown being impacted by flood water include the bridge to the tomb of Nefertari, the New Generator Building, the WC trailer, the security structures at the site entrance including the one where the metal detector is housed, the Bazaar, the parking area, and a number of areas of retaining walls.

Due to the absence of a drainage channel to the downstream side of the bridge to the tomb of Nefertari, flows beyond that point spread in an uncontrolled manner. This condition directly contributes to the projected flooding of a number of ancient and modern features mentioned above.

General recommendations emerging from the assessment

Priorities for interventions and their design are based on the significance of individual historic features, and in two tombs (QV 58 and 69) the archaeological materials stored in them. Most tombs on the south side of the main wadi also contain shale, which swells when it absorbs water. These tombs therefore also need priority for protection.

The primary approach advocated is prevention of floodwater and debris from entering by facilitation of rapid flow and evacuation of water and debris out of the Valley, and beyond the new orientation hall and new parking area (yet to be constructed) for safe dispersion in an area without archaeological remains. Recommendations follow the general principle of minimal intervention. In this respect, the height of diversion and protection walls should be minimized while still providing sufficient protection, and will be designed to visually blend into the landscape. Priority is also given to diversion of runoff to existing natural drainage channels rather than creating artificial channels. The following are a number of general proposals for flash flood protection:

- Deepen existing main drainage channel: The existing drainage channel should be deepened to provide greater capacity for water runoff and sediment flow.
- Extend main drainage channel to east and out of site: The main drainage channel should be extended to the east, beyond the location of the bridge to the tomb of Nefertari (which will have to be removed), to transport water runoff and debris out of the site and east of the parking area.
- Maintain main drainage channel: After construction of the new channel, regular cleaning of the entire length of the main channel must be carried out. If the channel is not maintained continually, its capacity to carry flood runoff and debris will diminish over time leading to flooding of the main wadi, including the new proposed orientation hall at the entrance to the site.
- Divert upslope runoff: Upslope runoff should be diverted away from at risk tombs on the north and south sides of the wadi and into the main drainage channel.
- Protect tomb entrances: A number of interventions are also proposed for the entrances of individual tombs to keep water and sediment out.
- Protect Deir er-Rumi: The ruins of the Coptic monastery, Romany sanctuary, and QV 95 at the site of Deir er-Rumi should be protected from upslope runoff.
- Dispose of flood water and debris beyond the Queens Valley: The main flood channel within the site will need to be extended beyond the parking area as a terminal discharge channel to safely dispose of the total flow outside the site.

Emergency preparedness and response plan

Past flash floods on the West Bank have been sudden occurrences resulting in the flow of enormous volumes of water and debris over short time periods. Based on the severity of the challenges faced by SCA personnel and other workers at Kings Valley in responding to the November 1994 flood, including the lack of essential emergency supplies and equipment close at hand, the 2001 flood protection study for Kings Valley prepared by the California Academy of Sciences and the Valley of the Kings Research Group recommended that the SCA have an emergency preparedness and response plan for future flooding. The SCA also should have such a plan for the southern sector of the West Bank, including QV, with the following measures:

- Emergency procedures: Procedures for specifying flood response actions and measures to avert or minimize damage by future floods. SCA personnel at Queens Valley and working in the southern sector should have annual training in procedures for implementing the plan.

- Emergency supplies and equipment: Equipment that is accessible in the southern sector of the West Bank for future flood response, including gasoline-powered water pumps and air driers, hand tools, and a vehicle to transport such equipment.

Table 5. QV tombs with reports or evidence of flooding or infiltration

Table 5 compiles evidence or reports of flooding or infiltration found within specific QV tombs. This evidence is classified into two categories: (1) recent evidence since the majority of QV tombs were cleared by CNRS in the 1980s, including from the last major flood event in November 1994; and (2) older evidence, which in most cases is in the form of tomb deterioration or damage that appears to be related to flooding or water infiltration. This evidence is displayed geographically in the map earlier in this section. The table also indicates which tombs appear to be vulnerable to flood from the main drainage channel, which tomb openings are in close proximity of drainage lines produced through GIS analysis with ArcHydro software, which tombs appear to have been affected by water infiltration through geologic faults or fractures, and in which tombs shale rock was observed. 19th and 20th Dynasty chamber tombs are indicated by shading.

Tomb	Reports or evidence of flooding/ Infiltration since clearing of tombs by Franco-Egyptian mission in 1980s	Evidence of flooding/infiltration prior to 1980s	Vulnerable from main drainage channel	Direct flow from drainage lines (ArcHydro)	Possible infiltration through fault / fracture	Shale observed
QV 3	Cracked, dried mud in Chamber B floor and ceiling (cleared 1984-5)		X			X
QV 4	Cracked, dried mud and debris in Chamber B on floor (cleared 1980s)		X			X
QV 7	Thick cracked, dried mud in Chamber B on floor and ceiling (cleared 1985-6)		X			X
QV 12	Thin cover of mud/silt on tomb floor (cleared 1986-7)		X			X
QV 20	Flooded in November 1994 (Leblanc, 2009, pers. comm.); collapsed massive rock on top of dried, cracked mud					X
QV 22	Thin cracked, dried mud at bottom of shaft and Chamber C entrance (cleared 1986-7)					X
QV 30	Thin cracked, dried mud in Chamber B on floor (cleared 1986)					X
QV 31		Loss of rock and decoration at the lower two-thirds of walls and around doors; horizontal staining and debris on walls of main chamber		X		X
QV 32	Cracked, dried mud on tomb floor (cleared 1985)					X
QV 34	Mud drip marks from earthen wall plasters throughout the tomb; in niche G, based on visual evidence, it appears that water entered adjacent tomb QV 35 and poured into the connected south Chamber G of QV 34 through a hole, causing complete loss of decoration in that area. Given that most of tomb's roof is collapsed, it presumably experienced water infiltration during November 1994 flood			X		X

Tomb	Reports or evidence of flooding/ Infiltration since clearing of tombs by Franco-Egyptian mission in 1980s	Evidence of flooding/infiltration prior to 1980s	Vulnerable from main drainage channel	Direct flow from drainage lines (ArcHydro)	Possible infiltration through fault / fracture	Shale observed
QV 35	As noted with respect to QV 34, it appears that flood water entered QV 35 and poured into the south Chamber G of QV 34, causing loss of decoration in that area. (cleared 1987)			X		
QV 36		On north wall of Chamber G, pitting of surface on lower half of wall may indicate salt and moisture-related deterioration, pointing to possible water infiltration.		X	X	X
QV 37	Cracked, dried mud on floors in Chamber C (cleared 1985)			X		
QV 38	Dried mud on floor of Chamber C to the west of entrance indicates past water infiltration in front part of tomb, which may have caused loss of repair plaster along base of wall to east of Doorway B.			X		
QV 39	Cracked, dried mud on floors in Chambers C, D, E (cleared 1987-8)			X		
QV 41	Large amount of upslope runoff flowed into tomb in November 1994 flood (Leblanc, 2009, pers. comm.)	Basal erosion of walls in Corridors C and F and Doorway E indicates likelihood of past flood damage.		X		
QV 42	Upslope runoff flowed into tomb in November 1994 flood (Leblanc, 1995, 212; Leblanc, 2009, pers. comm.)	Deterioration of pillars likely has been exacerbated by rock swelling and shrinking related to moisture from flooding events, and subsequent changes in lithostatic pressure.		X		
QV 43	Upslope runoff flowed into tomb in November 1994 flood (Leblanc, 1995, 212; Leblanc, 2009, pers. comm.)	Decoration and rock surface is uniformly lost along lower third of walls (approx. 0.5m high) in all chambers and along a diagonal slope in Corridor C, indicating level of debris or sediment fill that may have been associated with past flooding.		X		

Tomb	Reports or evidence of flooding/ Infiltration since clearing of tombs by Franco-Egyptian mission in 1980s	Evidence of flooding/infiltration prior to 1980s	Vulnerable from main drainage channel	Direct flow from drainage lines (ArcHydro)	Possible infiltration through fault / fracture	Shale observed
QV 44 OPEN	Small amount of water entered tomb in November 1994 flood (Leblanc, 2009, pers. comm.)	Loss of painted plaster at base of walls toward tomb entrance may indicate past flooding episodes.		X		
QV 47	Accumulations of silt and debris suggest possible past flood events that have contributed to the deterioration of the tomb (cleared 1984)					
QV 51		Complete loss of decoration at base of walls indicates a strong possibility of flooding .	X			
QV 53	Flood water and debris up to the mid-level of the tomb walls at time of 1994 flood (Leblanc, 1995, 212). Localized fallen rock present in multiple places on top of dried mud, indicating occurrence since 1994 event.		X			
QV 55 OPEN		Cracking and detachment of plaster on exterior ramp walls may be due to previous flooding or infiltration.	X			
QV58		Apparent water line about 0.5m high on its walls	X			
QV 60	Tomb flooded in November 1994 (Leblanc 1995, 212)	1m of sediment found in tomb by CNRS indicating 6 to 7 major floods (Messein et al., 1994, 480-481); sediment infill has caused deterioration of bedrock and wall decoration and floodwater has weakened bedrock up to 40 cm above sediment fill level.	X			
QV 61	Tomb flooded in November 1994 (Leblanc, 2008, pers. comm.)		X			
QV 62	Tomb flooded in November 1994 (Leblanc, 2008, pers. comm.)		X			
QV 63	Tomb flooded in November 1994 (Leblanc, 2007, pers. comm.).Dried mud on floor and ceiling.		X			
QV 64	Tomb flooded in November 1994 (Leblanc, 2008, pers. comm.); Dried mud on floor.		X			

Tomb	Reports or evidence of flooding/ Infiltration since clearing of tombs by Franco-Egyptian mission in 1980s	Evidence of flooding/infiltration prior to 1980s	Vulnerable from main drainage channel	Direct flow from drainage lines (ArcHydro)	Possible infiltration through fault / fracture	Shale observed
QV 65	Water reached the ceiling from November 1994 flood, requiring that 6 water tanks be extracted (Lebanc 1995, 213)		X			
QV 66		Schiaparelli reported the following about state of tomb in 1904 (translated from original Italian by GCI): "[t]he rubble, which had fallen upon [it] and had filled the stairs, had also entered in the first chamber [chamber (C)], where it piled up near the entrance, near the left wall and near the one in the back, almost touching the ceiling. The other chambers were almost empty; but their floor was evenly coated with a thick layer of soil, brought in by rain waters, which must have infiltrated the tomb repeatedly" (Schiaparelli 1924-1927, 53-55).			Fracture in rock of burial chamber ceiling and walls infilled with salt deposits	
QV 67	Dried mud on floor and ceiling (cleared 1987-8)					
QV 68	SCA chief guardian recalls removing water with buckets during November 1994 flood (2009, pers. comm.); Leblanc does not recall flooding.	Complete loss of painting at base of walls in upper chambers indicates likely flood damage, although survival of paintings in Chamber G relatively low to the ground suggests a low water level.			Fracture in rock of burial chamber ceiling and walls infilled with salt deposits	
QV 69	Cracked, dried mud on large area of floor of Chamber G and small area of floor of Chamber C (cleared 1987-8)					
QV 70	Dried mud adhered to walls from floor to almost level of ceiling (cleared 1984)					
QV 71	SCA chief guardian recalls removing water with buckets during November 1994 flood (2009, pers. comm.); Leblanc does not recall flooding.					
QV 73	SCA chief guardian recalls removing water with buckets during November 1994 flood (2009, pers. comm.); Leblanc does not recall flooding.				X	

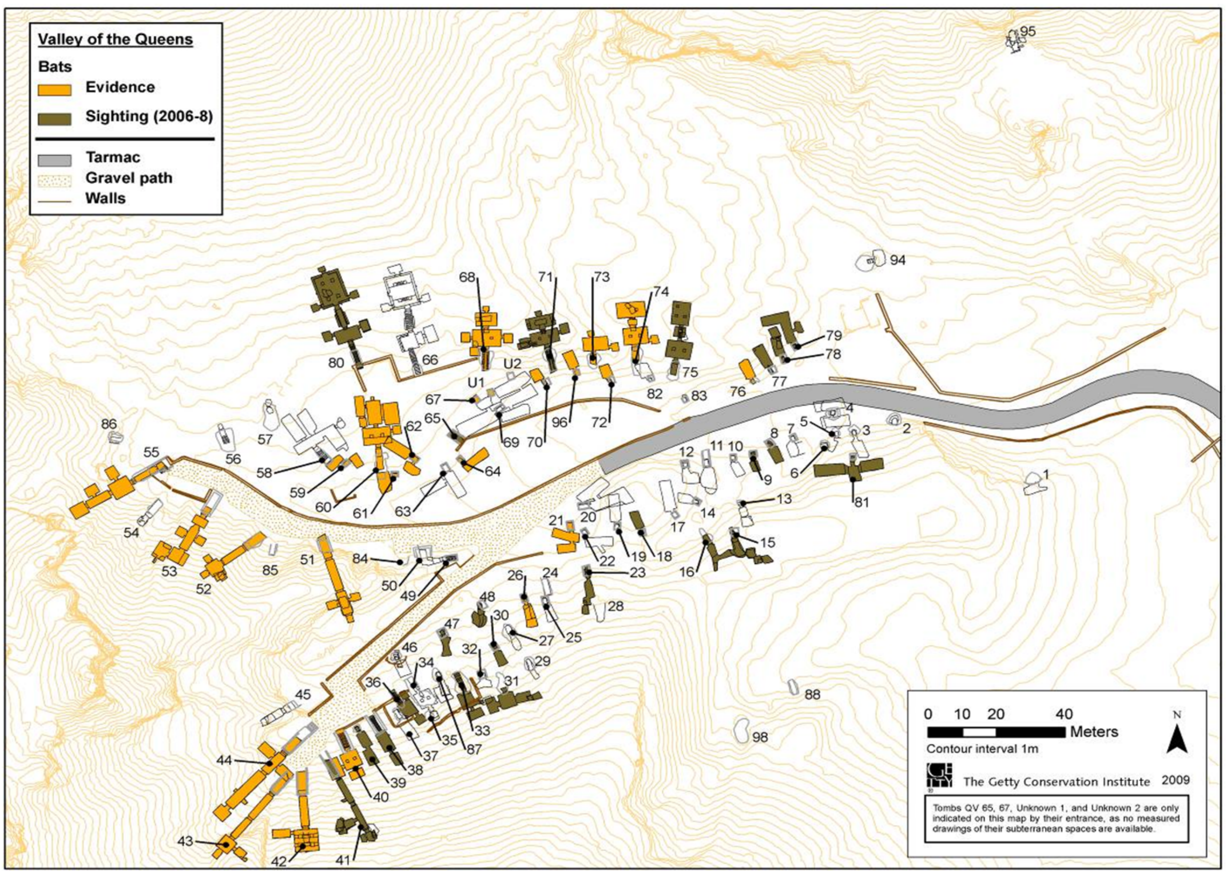
Tomb	Reports or evidence of flooding/ Infiltration since clearing of tombs by Franco-Egyptian mission in 1980s	Evidence of flooding/infiltration prior to 1980s	Vulnerable from main drainage channel	Direct flow from drainage lines (ArcHydro)	Possible infiltration through fault / fracture	Shale observed
QV 74		Loss of rock above entrance doorway (B) appears to be associated with exposure to rain water infiltration.				
QV 80		1970s CNRS photos before clearing show extensive debris; sediment line and loss of decoration in lower chambers visible in GCI assessment			Fracture in rock of burial chamber ceiling and walls infilled with salt deposits	
QV 81	Cracked, dried mud on floor in Chambers B and C; entrance at top of hill, so apparently flooded from QV 3 via connection between tombs (QV 3 cleared 1984-5; QV 81 cleared 1985-6)					
QV 82	Thin cracked, dried mud in floor of Chamber B (cleared 1986)					
QV 94	Alluvial debris in tomb shaft (cleared 1987)		X	X		
QV 96	Cracked, dried mud on floor (cleared 1987)					
U1	Cracked, dried mud on floor (cleared 1980s)					
U2	Cracked, dried mud on floor (cleared 1980s)					

Part V.3. Bat Colonies

The presence of bats is a vital part of the ecology of the West Bank, and the tombs of the Valley of the Queens provide good habitat for roosting colonies. At the same time, bats in tombs stain rock and decorated surfaces with their excrement and urine, and the deposits damage paint and plaster layers (Paine, 1993). Investigation by the GCI's Analytical Section of samples of white crystalline material from the walls of QV 75 showed (by FTIR) it to be mainly urea, with minor amounts of uric acid, organophosphate and a trace of possibly protein. This is consistent with the material being bat urine with admixed excreta. Evidence of bat induced mechanical damage has also been noted during the course of this assessment. Furthermore, pathogens borne both by bats and their feces are a potential health hazard (histoplasmosis and possibly rabies) for humans entering tombs. For these reasons, it is recommended that bats should be excluded from all except a few tombs in the Valley.

Distribution and concentration in tombs

Evidence of bats, either current or past, has been observed in forty-seven tombs. In nine tombs, bats were observed roosting in colonies of ten or more individuals. In an additional fourteen tombs, the bat concentration was less significant, but at least one individual was observed roosting or flying. In all other instances, the evidence of bat activity consists only of feces and urine deposits, and it is difficult to ascertain at what point bats were last active in the tomb and in what numbers. Generally, bat colonies appear to be particularly well established in tombs with deep internal shafts (QV 15, 23, 41, 75, 78), which are both darker and more secluded. Due to the relative inaccessibility of these internal shafts, the size of these colonies has been deduced by GCI team members from bat calls emanating from within as well as observation of bats flying in and out of the shaft entrances.



Map indicating the location of tombs where bats have been sighted from 2006-2008 (brown) as well as tombs where the presence of bats has been inferred from urine stains and feces (yellow). (Note: QV 55, 52, and 44 are lit and open to visitors; occupation by bats must pre-date visitation.)

Identification

Several different species of bat inhabit tombs in the Valley. Nevertheless, it can be difficult to visually identify the species of a particular bat solely on the basis of external characteristics. Christian Dietz, a bat ecologist at the University of Tuebingen, cautions in the introduction to his *Illustrated Identification Key to the Bats of Egypt* that variation amongst individuals of the same species can be considerable, and may not match descriptions in his guide (Dietz, 2005). Furthermore, the taxonomy of bats in Egypt has yet to be established with precision, and it remains possible that new species will be identified. Given these stipulations, Dietz was able to positively identify the presence of one species, *Rhinopoma hardwickii*, from a photograph taken in QV 36.

The photographs below illustrate some of the different kinds of bats observed in the Valley, with possible species identification based on the criteria of the *Illustrated Identification Key.* Dietz suggests that all of these species and more may be found roosting together in the tombs.

QV 36. Bat in rear chamber, identified by Dietz as *Rhinopoma hardwickii.*

QV 08. Possibly in *Pteropodidae* family.

QV 18. Possibly *Rhinolophus clivosus*

QV 80. Possibly *Taphozous perforatus*, known as the "Egyptian tomb bat."

Protection

According to the IUCN (International Union for the Conservation of Nature), *Rhinolophus clivosus, Taphozous perforatus,* and *Rhinopoma hardwickii* are all classified as species of "least concern," the least threatened designation on a seven-tiered scale used for evaluating the relative threat of extinction faced by a particular species (http://www.iucnredlist.org). It is regrettable that the essential role of bats in ecosystems as insectivores and pollinators is not widely appreciated, nor do bats enjoy any special protection under the provisions of Egyptian law. Even so, in keeping with international practices for interventions in historical structures with active bat colonies (Hutson, 1995; Howard, 2009), it is recommended that provisions be made to accommodate some of the bat colonies in the Valley by designating three tombs, presently occupied by bats, as their roosts.

Survey and relocation efforts

During the course of the assessment (2006-2008), members of the GCI-SCA project team as well as representatives from the SCA Conservation Centre in Cairo surveyed the tombs for bat activity, recording the presence of bats and evidence of habitation. On the basis of these cumulative observations, it was recommended in the GCI's proposal to the SCA of March 2009 that the majority of tombs be closed in such a way as to prevent the ingress of bats. The SCA's Conservation Centre also undertook the role of study and eventual relocation of bats from decorated tombs to three selected shaft tombs. This was to have involved input and guidance from the GCI. The Conservation Centre's role in the project was one of contributing to the inspection of tombs for sighting or evidence of bats, identification of bats to genus level and tentatively, species level. The Centre also carried out observations on breeding season including weaning (mid-March to early September) and dormancy or hibernation (December to early March). The Conservation Center advised that relocation should occur either from mid-March to July, the season when females are mating or pregnant, or from September to December, when they have weaned their young. Tests were undertaken using spotlights at the entrance to tombs and ultrasonic emitters (details not available) in order to deter bats from re-entering their roosting tombs. These tests were apparently successful and tombs QV 33, 41, 71, 75, and 80 were sealed in May 2009 with plastic sheeting on the entrance doors. As reported by the SCA Conservation Centre, these tombs were simultaneously disinfected, by using formaldehyde (whether in aqueous solution or gaseous is unknown). Prior to the eviction of bats in May 2009, swabs and air samples had been taken in April 2008 from the tombs. Laboratory culture by the Centre identified five species of fungi: *Aspergillus (fumigatus, flavus, niger, parasticus, sulphureus)*, *Penicillium chrysogenum*, *Rhizopus* species, and *Altenaria* species. It is not reported whether the fungus responsible for histoplasmosis (*Histoplasma capsulatum*) was tested for; if so, it was apparently not found.

At first, these measures successfully prevented bat reentry. However, due to wind and intense sunlight in the Valley, many of the plastic sheets had been torn or come loose by November 2009 and all of them were removed by the GCI at that time, having been deemed insufficient to exclude the bats due to the uncertainty of the period prior to the installation of new doors and shaft tomb covers.

Tombs identified a being suitable for permanent bat roosts are the 18th Dynasty tombs QV 15, QV 48, and QV 78 which have no decoration and no potential for visitation, and also host large colonies of bats. Since the bat colonies are well established in these tombs and they have already inflicted their damage, bat access will be permitted. Shaft surrounds for these tombs will be raised as necessary to prevent floodwater and debris entry; a metal grate with minimum 20cm openings will be installed to allow exit of bats and provide protection for visitors. It is recommended that species identification and behavioral information continue to be collected through the time of implementation. Success of the continued occupation of these tombs should be rigorously evaluated and this information and the approach to bat exclusion should be integrated into the site records for the Valley and made available as a reference for site management on the West Bank and elsewhere in Egypt.

In any case, bat eviction should occur immediately prior to the start of the planned tomb stabilization works in the Valley. The process should be guided by a phased and sensitive approach in which the impact on the colonies may be minimized. Finally, it should be mentioned that the impact of the new (2010) lighting of the West Bank mountains on the bat population is unknown and was not considered in any environmental impact study.

References

Dietz, Christian. *Illustrated Identification Key to the Bats of Egypt.* http://mammalwatching.com/Palearctic/Otherreports/Bat%20Key%20for%20Egypt.pdf. Accessed Dec. 10 2010.

Howard, Jonathan. Bats and Historic Buildings: the Importance of Making Informed Decisions. *Journal of Architectural Conservation.* November, 2009. pp. 81-100.

Hutson, A.M. Conservation of Bats in the Management of Ancient Monuments. *Managing Ancient Monuments: An Integrated Approach.* Clwyd County Council, 1995, pp. 71-78.

IUCN Redlist. http://www.iucnredlist.org. Accessed Dec. 10, 2010.

Paine, Stephen. The Effects of Bat Excreta on Wall Paintings. *The Conservator.* No. 17, 1993, pp. 3-10.

Summary Table of Bat Evidence

Tomb	*Bat Evidence*
QV 08	Possible *Pteropodidae* observed Jan 2008
QV 09	1 observed Jan 2008
QV 10	droppings
QV 15	approx. 100 possible *Rhinopoma* noted in rear shaft in Jan 2008, Dec 2009
QV 16	droppings
QV 18	Possible *Rhinolophus clivosus* observed Jan 2008
QV 21	droppings
QV 23	Many bats heard in lower shaft
QV 30	1 seen Jan 2008
QV 31	Possible *Rhinopoma* seen in side shaft, Jan 2008
QV 32	One bat seen Jan 2008
QV 33	2-3 seen in main chamber in 2006, 2007, 2008; possibly more in side shaft
QV 36	1 *Rhinopoma hardwickii* (identified in photograph by Christian Dietz) seen in 2007
QV 38	bats observed in April 2008
QV 39	large number observed in Feb 2008
QV 40	urine staining
QV 41	Large number in two interior shafts, seen in 2006, 2007, 2008

Tomb	*Bat Evidence*
QV 42	extensive staining from urine
QV 44 OPEN	signs of previous activity
QV 46	droppings
QV 47	3 observed in Jan 2008
QV 48	at least 15 bats observed, possible *Rhinopoma hardwickii* and *microphyllum*, Jan 2008
QV 51	urine staining in rear of tomb
QV 52 OPEN	signs of previous activity
QV 53	signs of previous activity
QV 55 OPEN	signs of previous activity
QV 59	droppings and urine staining
QV 60	localized areas of urine staining
QV 61	Urine staining
QV 62	Droppings and staining
QV 64	Urine staining
QV 65	2-3 bats, possibly *Rhinopoma*, observed in Jan 2008; more than 10 bats observed in Dec 2009
QV 67	droppings
QV 68	Signs of previous activity
QV 70	droppings
QV 71	Several bats observed in 2006 and 2007; extensive staining and droppings

Tomb	*Bat Evidence*
QV 72	Droppings and urine staining
QV 73	signs of previous activity
QV 74	Signs of previous activity
QV 75	Several bats observed in Jan 2008, more in deep central shaft
QV 77	1 bat observed in Nov 2007
QV 78	10 observed in main chamber, many more seen and heard in rear shaft in Jan 2008
QV 79	5 bats, possibly all *Rhinopoma hardwickii* seen in Jan 2008
QV 80	A large number observed in 2007 and 2008, possibly some *Taphozous perforatus*
QV 81	At least one bat observed in Jan 2008
QV 96	droppings
QV Unknown 1	Droppings and urine staining

Decorated Tomb