James McLane and Raphael Wüst

Flood Hazards and Protection Measures in the Valley of the Kings

The Valley of the Kings (VOK) contains 62 numbered tombs from the 18th, 19th, and 20th dynasties, the New Kingdom period of ancient Egypt that flourished during the 16th through the 11th centuries, B.C. Of these, 22 tombs show evidence of royal occupancy. The VOK is located on the west bank of the Nile in the region of ancient Thebes, which also comprises the present-day town of Luxor on the east bank. Hundreds of underground tombs built as the final resting places for kings, queens, and nobles are today preserved as part of the Theban Necropolis, which also includes temples and other ancient sacred structures interspersed with pastoral villages. The Supreme Council of Antiquities (SCA), Egypt's governmental agency in charge of these sites, must balance its preservation objectives with the heavy impacts of tourism.

The authors are members of a research team that is preparing a master plan in an attempt to mitigate the impact of flooding on the tombs in the VOK. The Valley of the Kings Research Group (VOKRG), which consists of American, Canadian, and Egyptian professionals from various disciplines, is sponsored by the California Academy of Sciences and is working in collaboration with the SCA.* The project, funded by the United States Agency for International Development (USAID), is carried out and administered by the American Research Center in Egypt (ARCE) under USAID Grant No. 263-G-00-93-00089-00, "Restoration and Preservation of Egyptian Antiquities Project."

General view of the Valley of the Kings looking south. The peak at upper left is the Gebel el-Qurn, the high point of the drainage area, 283 meters above the floor of the Valley. At lower right is the entrance to the tomb of Ramesses VI, labeled KV-9. Left of that tomb, a crowd of tourists is queued in the main walkway, entering the tomb of Ramesses III, KV-11. Photo by James McLane.

The Site and its Context

The VOK is a large *wadi* on the northern slope of a peak known as Gebel el-Qurn, with a drainage area of 0.46 sq. km. The tombs were cut out of the native marls that underlie the cliffs and slopes of the valley. They were decorated by painted plaster reliefs that illustrated liturgical scenes, and they are now some of Egypt's most highly valued antiquities. Historical records and physical evidence indicate that, since antiquity, there has been a succession of infrequent but heavy rains that have caused flooding of the tombs. Water drains from the upper catchment basin into the narrow gullies at the valley floor, which have been converted in modern times to the walkways used by tourists to access the tomb entrances. These have acted as the primary drainage channels in flood events, allowing water to drain into the tomb entrances. Flood water and sediment have stained and abraded the tomb decoration, caused migration of salts to the painted plaster surfaces, and damaged some tomb walls and pillars by causing the underlying shale to expand and thereby impose excessive stresses on the rock structure.

In October and November of 1994, two flood events occurred in the VOK, sending a warning to all heritage managers. In both cases, a local desert rainstorm occurred in the vicinity of the VOK. Storm-water runoff and sediment entered many of the tombs and caused erosion of gully floors. The SCA and ARCE responded by setting a project in place that would analyze the problems and implement a plan of action.

Scope of the Flood Protection Project

VOKRG worked under the careful supervision of ARCE to define the project's approach. The project scope of work is summarized as follows:

- Conduct a historical survey of documents pertaining to flooding in the valley, as well as information on topography, climate, and excavation activity.
- Conduct a field survey of the valley topography, geology, and existing surface structures; interior tomb surveys of geological conditions; and architectural documentation of the tombs (final products include topographic map, geological map, measured drawings of tombs, photographic documentation of valley topographic features, tomb entrances, and tomb interiors).
- Perform analysis of topography, geology, and hydrology.
- Prepare a master plan for the valley that specifies flood protection measures that apply to the entire valley as well as to local areas or individual tombs.
- Recommend a program for monitoring geological and climate data in designated tombs.
- Recommend and, if approved, construct two prototype flood protection measures.

Surveys: Topographic, Architectural, and Geological

VOKRG has made two field expeditions, one of four weeks, another of three weeks, for the purpose of surveying existing conditions.

The team studied ancient maps of the VOK in order to ascertain how over the centuries the valley has been altered by flood events and excavation activity. The most recent map of the valley, prepared by the Institut Geographic National (IGN) of France in 1962, was updated. An accurate survey using conventional methods but modern equipment produced a map which includes ground topography, tomb entrance structures, the existing walkway system, and other modern structures that accommodate tourism. Hydrological profiles were drawn from this survey data and used in the later analysis.

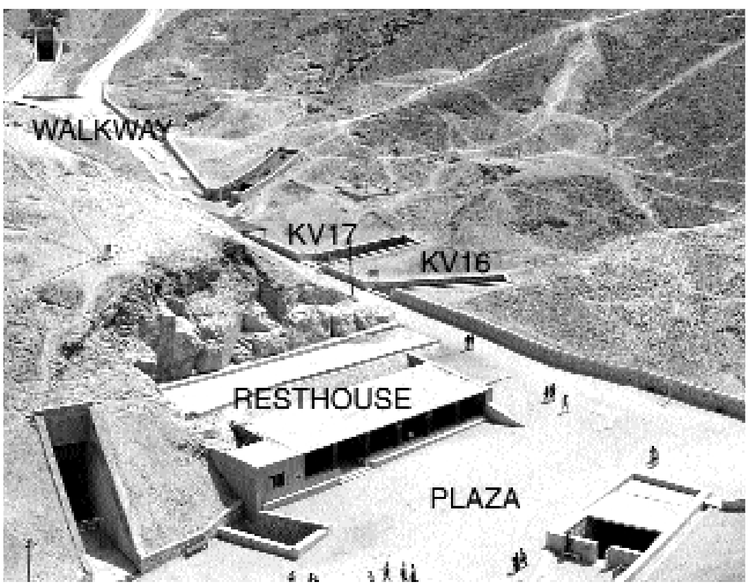
A team of architects worked in parallel on a survey of the tombs' interior chambers, producing a set of measured architectural drawings. The final product of both of these teams was a three-dimensional computer assisted design (CAD) map that shows surface topographic features as well as the subterranean architecture of the tombs. This document can serve as a base for future researchers to document the decoration in the tombs, and to implement further preservation measures.

A team of two geologists prepared a geological map that shows bedrock type, thickness of flood and excavation debris and, most importantly, catchment areas and flash flood flow patterns.

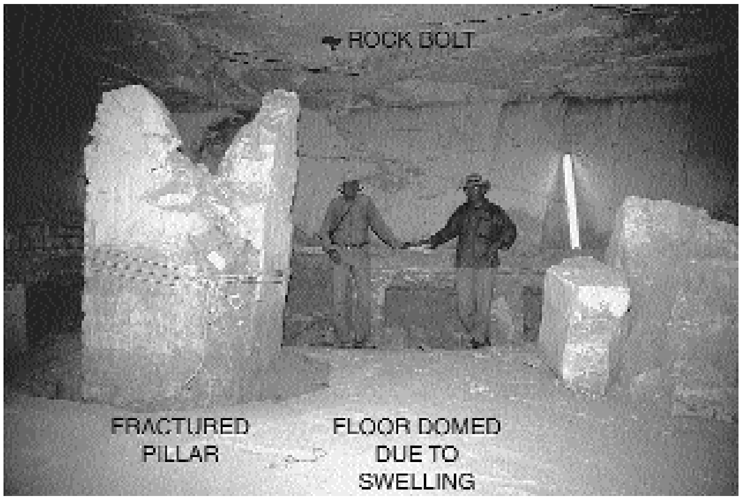
Analysis: Geology, Hydrology

The Thebes Mountains are composed of 350-meter-thick Eocene marls and limestones (Thebes Formation) overlying a 60-meter-thick Paleocene/Eocene shale (Esna Formation). Most tombs are built into the lowermost marl unit of the Thebes Formation, but some of them extend down into the Esna shale. During uplift of the Thebes Mountains, the brittle marls and limestones fractured and one of the Graben structures crosses the VOK. The displacement of rock units prior to the tomb excavation resulted in abundant rock joints, which can be re-activated during earthquakes or other rapid stress releases such as by swelling of the shales. When water enters the tombs, it comes into contact with the shale at the lower chambers, and causes swelling, cracking and structural failures in the floors, walls, and pillars.

Several tombs had been protected against floods by ancient Egyptian constructions. Unfortunately, most of them have been severely damaged during the past 3,000 years and are no longer effective. The researchers plotted floodwater flow paths and calculated the maximum amount of runoff for each tomb. With no local weather data available, the hydrologist based rainfall estimates on flash flood events in similar desert climate areas for which reliable data could be obtained. The hydrologic analysis sought to estimate the two major characteristics of the maximum flood event that may occur. The first and most basic characteristic is the maximum eleva-



Detail view of one of the main walkways, with resthouse and plaza. The walkways act as drainage channels during flood events. Walls about one meter high, made of dry-laid rubble with a concrete cap, line the walkways. Note the tomb entrances to KV-16 and KV–17, which are typical in that they are accessed by descending a stair from an adjacent walkway. Photo by Roy Eisenhardt.



Interior view of a lower chamber in the tomb of Ramesses II, KV-7, an example of the damage caused by successive flood events. Virtually all of the decorative plaster reliefs are lost, and the rock structure has been heavily impacted by swelling of the underlying shale. The floor obscures the two team members' feet because it has swelled in the center. There are two rock pillars on either side that have fractured and collapsed. At the top is a rock bolt installed by another project in a recent effort to forestall further spalling of the ceiling. Photo by James McLane.

tion, or depth, of the water surface of the flood as it passes the entrances of the tombs. If the elevation becomes higher than the top of the wall surrounding the entrance, flooding of the tomb results, as has been the problem for many tombs. The second characteristic is the velocity of the water stream during a flood event. The higher the velocity, the greater the energy in the water with a potential to cause scour, undermining walls or protective structures and ultimately creating a water path into the tombs.

By establishing the water depth in front of any tomb entrance during a flood event, structures can be designed to prevent the water from entering the tomb. The main variables that determine the water depth are the quantity of water being discharged, the width of the channel, the slope of the channel, and the roughness of the channel. By establishing the velocity of the water stream, an estimate of the size and quantity of sediment that will be transported can be made as well as an estimate of the energy and potential scour that could occur.

The calculated water surface elevations indicated that each tomb should have a protective wall at the entrance with a height of 0.25 to 1.00 meter above the adjacent walkway, depending on the location. Equally important is that the walkways provide an adequate channel to convey the water away downstream. No constrictions should occur moving downstream, or if there must be a constriction, it should be gradual and smooth. In addition, all of the walls that form walkways should be filled with cement and finished smooth both to provide strength during the turbulent water flow and to decrease the channel roughness and therefore convey more water at a lesser depth.

Recommendations

The team incorporated input from the SCA, workers in the valley, and eyewitnesses of the 1994 flood events. The recommendations had to consider every possible approach, yet work within the limitations of technology and financial resources. They are grouped in five categories, with the salient elements briefly noted:

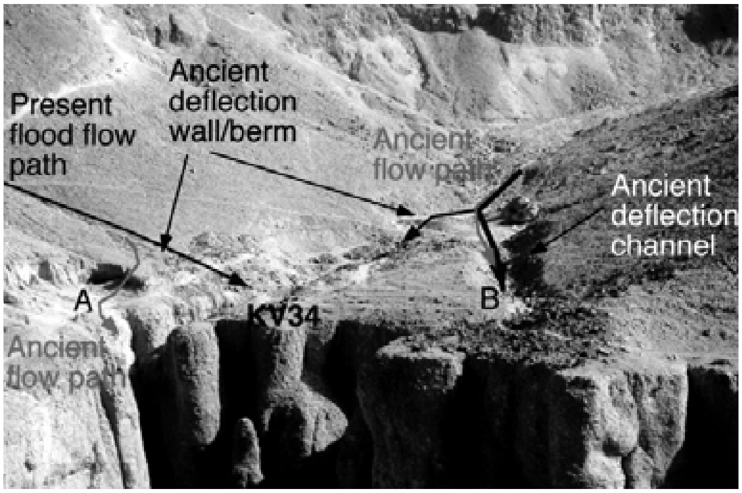
Long-Range Planning. The final report may serve as a database that can enable resource managers to control floodwater flow patterns. The survey maps show existing conditions, while the new map of proposed measures will show the work to be completed. The hydrological map will show how flow patterns will be re-directed by the proposed protection measures.

Emergency Response Plan. Analysis of the 1994 flood events revealed that a response plan would be an essential element of a preservation program. In addition to producing a training guide with base information about the flood hazards, it was proposed to put in place equipment such as a water pump, air dryer, hand tools, and a transport vehicle. This equipment could be used to avert or minimize damage by future flash floods.

Low-Cost/No-Cost Protection Measures. These measures involve minor changes and additions to existing procedures used by the dedicated staff in the VOK, who work with very limited resources to maintain a resource that is subject to intense impact by tourists who have little understanding of their difficult conditions. These include

- an improved program of monitoring tomb climate data collectors
- a related program of monitoring deterioration of the tombs' rock structure and their decorated surfaces
- the preparation of an as-built plan of the existing utility system
- implementing a plan to document the numerous minor repairs that are done to the tombs
- suggestions regarding limiting access by tourists.

Large-Scale Protection Measures. The core of the plan is the specific measures proposed to be constructed. The team will implement two of these measures as prototypes for the final stage of the project. One of the two prototypes will be to reconstruct an ancient rock berm that was built as a diversion structure above one of the oldest tombs (Tuthmosis III). The second prototype



View of the proposed restoration of the ancient deflection wall, which lies at the bottom of the upper drainage basin, directly above the tomb of Tuthmosis III, KV-34. Photo by Raphael Wüst.

will be construction of a new entrance walkway structure that will provide access to two tombs (Seti I and Ramesses I), while diverting floodwater in the adjacent walkways away from the tomb entrances.

The general measures include

- clearing the upper VOK basin of loose sediment and debris where future floods may sweep them into the tombs
- similar clearing in the areas directly above all tomb entrances
- widening and removing obstructions from the main walkways, which act as water channels during flood events
- reconstructing an ancient diversion structure in one part of the valley that would divert floodwater from a group of tombs with high preservation priority.

Protection Measures for Individual Tombs. The plan includes such detail as to provide an extensive list of recommendations for each tomb. Many of these measures have already been implemented by the SCA in isolated instances. They may be summarized as follows:

- Increase the height of and make waterproof the walls that surround the tomb entrances
- Construct watertight channels for diverting floodwater around the tomb entrance protection walls
- Seal open joints in the rock surface above the tombs in order to prevent leakage
- Build concrete roofs above tomb entrances that are exposed to falling water from overhanging cliffs
- Install steel doors at tomb entrances in order to prevent floodwater and debris from entering
- Install additional flooring, stairs, and glass screens in tombs that receive the highest influx of tourists, in order to minimize the damaging effects of abrasion and increased temperature and humidity
- Install air-conditioning systems and monitoring equipment in the highest priority tombs
- Seal the entrances with permanent doors (or by backfilling them permanently) for tombs that are seldom entered or are of low priority.

Note

* The Valley of the Kings Research Group (VOKRG) consisted of the authors and Lyla Pinch Brock and Ted Brock, Egyptologists; Charles Cecil, anthropologist; Garniss Curtis, geologist; Roy Eisenhardt, photographer and co-director; George Homsey, architect; Brad Porter, civil engineer; John Rutherford, civil engineer and project director; Dr. Abdul Fattah el-Sabahy, Egyptologist and project coordinator; Britt Stitt, construction consultant. Officers of the SCA (Mohamed Mohamed el-Saghir, Sabri Abdel-Aziz Khater, Mohamed El-Bialy, and Ibrahim Soliman) and many other unnamed employees at the VOK provided valuable assistance.

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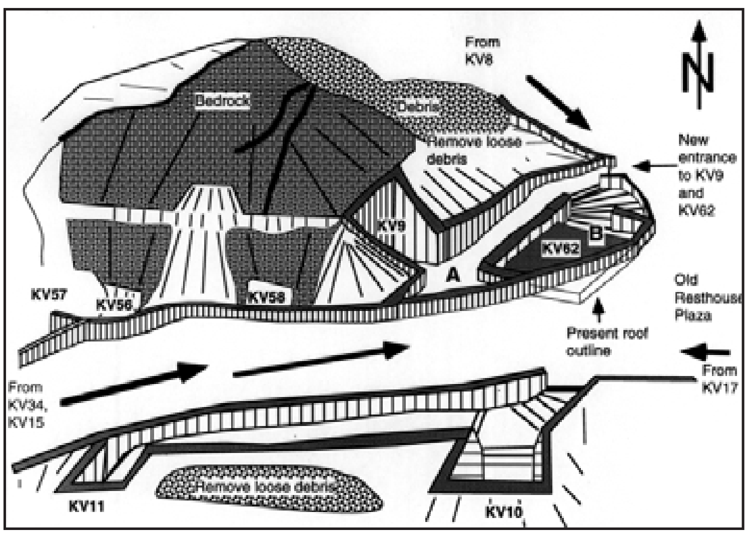

An example of flood protection measures as illustrated by Raphael Wüst. KV numbers refer to tombs. Newly configured walls along the walkways would direct the flow of floodwater away from the tombs with fewer obstructions or constrictions.