# MACHU PICCHU:
# PREHISTORIC SUSTAINABLE WATER SYSTEMS

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*The Inca civil engineers designed for sustainability as well as aesthetics. Decade-long field studies at the Pre-Columbian archaeological site of Machu Picchu revealed that the Inca possessed an uncanny ability to design structures that endure. This is evident in the vast amount of Inca construction that still exists for us to study and admire. The crux of these remarkable skills, superb drainage, structural and foundation design, existed in the absence of a written language, use of the wheel, or the availability of iron or steel.*

## MACHU PICCHU

Established in A.D. 1450, Machu Picchu was the royal estate of the Inca Ruler Pachacuti. It is the essence of ancient sustainable design. The site is located 450 meters above the valley bottom on a mountain ridge between the prominent mountain peaks of Machu Picchu and Huayna Picchu. The site is a remarkable example of Inca ingenuity in the face of challenging natural topography and environment.

The well-preserved remains of Machu Picchu show that they had an advanced understanding of drainage and foundation design, the cornerstones of sustainability. Difficult site constraints existed at Machu Picchu associated with the nearly 2,000 millimeters per year of rainfall, steep slopes, landslides and remoteness.

## Agricultural Terraces

The agricultural terraces of the Inca royal retreat of Machu Picchu are visually dominating. They complement the magnificent structures of this mountain-top sanctuary both physically and aesthetically. The terraces also provided protection from excessive runoff and hillside erosion.

The numerous ancient agricultural terraces total 4.9 hectares. They are formed by stone retaining walls, contain thick topsoil, and are well drained. The analyses of soils showed that the sandy loam topsoil was thick. The deeper Strata II and III soils were more granular than the Strata I topsoil, which provided for higher permeability to enhance subsurface drainage. In deeper strata the Inca workmen provided for excellent subsurface flow paths with loosely packed large stones, and sometimes with stone chips from the stonecutting efforts (Valencia and Gibaja 1992).

We conducted field investigations to define the agricultural drainage. The canal that furnished water to the fountains in the urban area of Machu Picchu traverses the agricultural sector, but there are no turnouts to the terraces. We also performed field investigations to determine whether surface drainage water was reused for irrigation purposes. No evidence of reuse of surface drainage for irrigation was found within the Machu Picchu ruin. Neither was the discharge from the domestic water supply fountains directly reused for irrigation, but merely discharged to the Main Drain. However, evidence was found which shows that subsurface drainage water was captured for several stone-formed fountains among the lower terraces downhill from Machu Picchu.

Our inspection of the terraces and the examination of photographs taken of Machu Picchu in 1912 by Hiram Bingham indicated little erosional evidence from surface runoff, even after nearly four centuries of no maintenance and significant rainfall. The surface infiltration of rainfall to the subsoil drainage system was highly effective. The parallel surface drainage system for the agricultural terraces, for the most part, provided redundancy and a drainage safety factor for intense rainstorm events.

**Urban Surface Runoff Criteria for Inca Wall Drainage Outlets**

| PRIMARY | MAGNITUDE |
|---|---|
| Tributary area per drainage outlet | 200 $m^2$ |
| Drainage outlet size, typical | 10 cm by 13 cm |
| Drainage outlet capacity, maximum | 650 l/min |
| Design rainfall intensity | 200 mm/hour |
| Rational formula runoff "C" | 0.8 |
| Design flow per drainage outlet | 500 l/min |

## Urban Sector

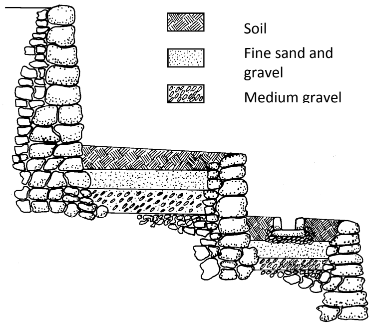
The Urban Sector of Machu Picchu covers 8.5 hectares and contains approximately 172 buildings, most of which were covered with thatched roofs. These residential and temple areas of Machu Picchu were laced with granite stairways and walkways, of which many also provided routes for drainage channels. Situated throughout the urban development in the retaining walls and building walls are numerous surface drainage outlets which, when coupled with the drainage channels and subterranean caves, define the surface drainage network. The density of thatched-roof buildings resulted in a generally high coefficient of runoff with a short time of concentration for the rainfall-runoff relationships.

The studies of Machu Picchu resulted in the finding that its drainage system has ten major components, summarized as follows.

1. A centralized Main Drain separating the Agricultural Sector from the Urban Sector.

2. Agricultural terrace surface drainage with reasonable longitudinal slopes, leading to formal surface channels integrated with terrace access stairways or the Main Drain.

3. Subsurface agricultural drainage at depth typically consisting of larger stones overlain with a layer of gravel and above that a layer of somewhat sandy material.




4. Drainage management of the unused domestic water supply.

5. Positive surface drainage of urban grass or soils to drain the runoff from the many thatched roof structures and plaza areas. In some places, thatched roof drip channels exist.

6. Urban and agricultural drainage channels combined with stairways, walkways, or temple interiors.

7. Deep subsurface strata under plazas of rock chips and stones to allow the plaza to receive and infiltrate runoff from tributary areas.

8. A well-conceived and strategically-placed urban area system of 129 drain outlets placed in the numerous stone retaining and building walls.

9. Subterranean caves with relatively free subsurface flow via natural underlying permeable deposits of decomposed granite and rocks.

10. Formalized systems for intercepting groundwater drainage on the lower east flank of the mountain ridge for serving ceremonial and utilitarian fountains.

Without good drainage and foundation construction, there would not be much left of the royal estate of Emperor Pachacuti. The buildings would have crumbled and many of the terraces would have collapsed due to the high rainfall, steep slopes, slide-prone soils, and settlement.

Surface and subsurface drainage at Machu Picchu were given high priority during its design and construction. One can say that the miracle of Machu Picchu is not only the beautiful buildings that have been the subject of past archeological studies, but also the engineering features that lie unseen beneath the ground where an estimated 60 percent of the Inca construction effort centered.

**SUSTAINABILITY**

The Inca surface and subsurface drainage works were extensive and effective. They used empirical relationships between area and runoff to locate and size drainage outlets in their walls.

Inca water development at Machu Picchu was not only site-specific, as described above, but sustainable, as evidenced by the fact that so much of the Inca water resource infrastructure remains for our study. One reason we know about Inca water resources development is because of the great care taken by the Inca in incorporating adequate foundation drainage. Trouble was also taken by the Inca to maintain the purity of the domestic water supply by directing agricultural and urban storm water discharges away from the open domestic water supply canals. They also designed excellent foundations that allowed many features to last indefinitely.

Technical analysis of the Inca drainage works demonstrates that the drainage criteria used were reasonable and the implementation uncanny. We can thank the site preparation and drainage work of the Inca for the fact that so much of their work has endured into the twenty-first century.

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