WATER ARCHITECTURE IN THE LANDS OF SYRIA:
THE WATER-WHEELS

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Volume 1: Text

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THESIS ABSTRACT

This thesis aims to evaluate the typology of water-wheels in Syria as an ancient type of water architecture which has had a fundamental role, over the centuries, for irrigation and supplying water to houses and public constructions. So far these devices have been studied in terms of their hydraulic and technological aspects, while their architectural and artistic qualities have often been neglected. The research provides a historical, architectural and iconographical study of these structures, focusing on those located in West Syria, where most water-wheels were built and have high artistic value. The study looks at their architectural aspects and artistic significance, and identifies precise classifications by examining the shape and design of the installations.

The thesis develops in three parts. The first part presents a detailed analysis of the typology and sources related to its origin and development. The second part, mainly based on architectural material and on the results of fieldwork done on the sites, highlights the cultural, historical and architectural value of the Syrian installations, showing their significant characteristics and advantages, the reasons of their uniqueness and of their wide diffusion until recent times. The third part deals with the relationship between water-wheels and modern irrigation systems, and attempts to evaluate the feasibility of renovating water-wheels as a sustainable system, as well as an example of historical and cultural heritage.
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FOREWORD

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I would like also to acknowledge the Barakat Trust, the British Society for Middle Eastern Studies (BRISMES) and the Institut Français d'Études Arabes de Damas (IFEAD) for financial support during my fieldwork in Syria.

2. NOTES ON CONVENTIONS

Drawings and photographic illustrations are bound in a separate volume (Volume Two) and indicated in the text by “Fig.” in brackets. At the end of Chapter Eight there is an illustrated glossary of architectural terms utilised throughout the text. Beside each term the corresponding word transliterated from Arabic is shown in brackets, while Arab and Latin words are used where an English translation does
not exist. Dates associated with Islamic history are given in *hijrī* and Gregorian terms where of particular significance. In this case the *hijrī* precedes the Gregorian. Otherwise, only the Gregorian equivalent is used. The transliteration of Arabic follows the *International Journal of Middle East Studies* system. Throughout the text, international modern names of rivers, towns and sites, are used (for example, Orontes, Aleppo, Ḥoms, Babylon, etc.). Some installations referred to in this thesis have not been published before, and their spelling is based on the verbal testimony of local people. The transliteration of Akkadian words follows the Assyriological Convention.
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Kazo al-Kabīra

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Aqueduct “Los Milagros”, Mérida, Spain, 1st century A.D. (Hodge 1992, fig. 117, p. 163)


Arch of Titus, Rome, 25 B.C.

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CHAPTER SIX

Al-Hajj birka at Bosra

The barrage of the Qaṭṭīna lake

The barrage of Rastan

The barrage of Rastan

The barrage of Maḥarda

The Ghāb plain

The Orontes river in the Ghāb plain

An irrigation channel in the Ghāb

The broken dam at Zayzūn

An irrigation channel between Apamea and Karkūr showing a succession of electrical pumps raising water to irrigate the Ghāb fields

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Ḥamā: al-Ma’muriyya hydraulic noria with a new building abutting the aqueduct

Southern Ḥamā: al-Wajīyyat hydraulic noria with a new building abutting the aqueduct

Damascus, garden of the National Museum: wheel and triangle belonging to a model of a hydraulic noria on the Orontes
452 Damascus, garden of the National Museum: model of a hydraulic noria on the Orontes. The aqueduct is orientated parallel to the wheel, unlike the actual orientation.
CHAPTER ONE

INTRODUCTION

1. SYRIAN WATER-WHEELS: AN AGE-OLD TRADITION

Many techniques were used in Syria to lift and convey water from rivers and wells. The most impressive device used was the water-wheel, driven by waterpower or by animals. Water-wheels have played a leading role in a centuries-old tradition, in solving the main problem of supplying and carrying water for irrigation in Syria. Although this typology has had a fundamental role, it has been considerably underrated in art-historical writing.

Water-wheels have been studied in terms of hydraulic and technological aspects, while their architectural qualities have often been neglected. A reason for the neglect of this type of water architecture is that it has long been regarded as merely utilitarian, while its artistic connotations have largely been ignored. In addition the fact that most installations are located in isolated areas, difficult to reach, may have contributed to a scanty consideration of Syrian water wheels.

Another reason for the lack of attention paid to these water-structures may be the fact that they have been strictly connected with the environment in which they are used, and have been correlated with the availability of surface water and groundwater. This means that their spectacular aspects and the function of their

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1 Although the correct Arabic terms for water-wheels are nā'ura and sāqiya, throughout the text I have used the term noria in the singular and norias in the plural, because this is a universal definition used across Europe and the Middle East. Since there is no English version of sāqiya, I have employed the Arabic term, using sāqiya in the singular and sāqiyas in the plural.
technology can be fully appreciated when the wheel is in motion. Many installations have, in fact, been completely abandoned and have fallen into disuse when people looked for new technologies which provided water much more easily.

My present research deals with the analysis of Syrian water-wheels, which were built specifically to raise water for irrigation rather than to move machinery, starting from a study of the origin of the typology and its problems in terms of terminology and classification, focusing on their architectural aspects and artistic significance, and identifying precise typological differentiation by examining the shape and design of the structures. The study focuses on the water-structures used to supply water for irrigation located in western Syria, where most installations were built and, as will be shown, have evidenced a high artistic and historical value. The Syrian structures have also been evaluated as part of a wider geographical context where different regional variations have developed over the centuries. An appropriate assessment for the implementation of sustainable renovation of water-wheels has been attempted through a possible re-evaluation of these traditional types of water-architecture.

2 The few remains of installations in East Syria are dealt with only in terms of any major differences with the greater number of water-wheels which have survived in West Syria on which this thesis focuses.
2. SOURCE MATERIALS AND APPROACH

In this study, historical records, together with the results of fieldwork, have provided a clear picture of the importance of Syrian water-wheels. Various types of material have been used in order to make possible a better understanding and interpretation of these water structures. As in Syria some water-wheels are no longer in working order, the main sources of information are written texts and visual material.

The thesis includes information found in treatises on architecture and hydraulic manuals, which have been used as a foundation to explain technological matters and the shapes of water-wheels.

The knowledge of medieval machinery which has permitted an understanding of the technological development and evolution of the water-structures is also derived from manuscripts and books which have provided an accurate picture of the application of such machines.

For the history of these machines our best sources are travel books and topographical works which have revealed the centuries-old tradition of water-wheels and underlined their historical importance.

The thesis also includes information derived from papyri, mosaics and mural paintings, and the results of archaeological excavations. They have allowed a better understanding of the historical evidence and development of water-wheels. Inscriptions on some installations have also been used to assist in dating and recording construction and restoration work.
The sources of information have been combined with the results of fieldwork. Architectural data are based mainly on surveys and studies of the water-structures located in Western Syria. More than one hundred sites characterized by the presence of water-wheels have been surveyed. All findings, apart from the significant machine preserved in Damascus, are concentrated in the Orontes valley. In Aleppo and Homs no remains have survived and their study is based on historical information and old reproductions.

Fieldwork done in two different seasons has allowed an exhaustive survey of the Orontes installations. In a period of low water level, as in autumn 2004, it was possible to study the complete structures, including the foundations, allowing the exact type of installation to be determined. By contrast, in spring 2005, when the river level was high enough to enable the water-structures in use to work properly, it was possible to gain a better understanding of their efficiency. Several structures have never been documented before, and are illustrated by photographs and drawings which permit a deeper understanding of these installations.

Despite the fact that the Orontes installations have been traditionally considered as based on only a single pattern, it will be shown that a variety of shapes and designs was adopted. Frequent repairs and reconstructions, and the lack of well-preserved structures from earliest periods, make dating extremely difficult. An attempt has been made to understand the possible original aqueduct and tower designs. Through this study, the results based on fieldwork combined with historical data will establish a working hypothesis rather than a definitive statement.
The study of the installations surveyed was structured in three phases. The first step was to analyse the structures and identify precise typological classifications. Secondly, by examining building techniques and architectural details, and by a comparative analysis of the installations with different ancient typologies, and with the support of historical manuals and treatises on architecture, it was possible to identify the probable original shape and to understand the evolution and development of the typology. Finally some significant examples, whose design shows interesting degrees of elaboration, have been selected and analysed in more depth, also representing the main design types of the Orontes installations.

Fieldwork has also aimed to verify the existence of remains of ancient water-wheels powered by animals, which raised water from underground, and once existed in the rural areas of north-western Syria. The most recent documentation of the last few remains dates back to Schişler’s survey of the 1970s. The surveys that I have done in these areas have ascertained the loss of surface remains of these devices. However, as will be argued, these devices have been particularly considered for their functional and utilitarian aspects, rather than for architectural characteristics, and their study has mainly been based on historical material and old reproductions.

Fieldwork has also included a survey of the modern systems of irrigation built along the Orontes, and has allowed an understanding of the relationships with traditional water-wheels powered by the river (hydraulic norias), how and why modern systems of irrigation replaced them, and how a re-evaluation of these traditional water-structures may be possible.

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The study of Syrian hydraulic norias has clarified the uniqueness of these devices, also compared with important installations still in use in other parts of the world, in particular the Chinese examples. In order to better understand their structure and to compare them with Syrian examples, Chinese water-wheels located in the Guangxi region have been surveyed. These installations, which are numerous along the Linxi river, represent a characteristic typology which is widespread in East Asia. The fact that they are still in use to irrigate large rice fields has enabled a better understanding of their architectural details and a clear comparison with the Syrian examples.

3. RELEVANT AVAILABLE LITERATURE

Despite the general neglect of the subject, it is appropriate to consider the relevant literature devoted to the history of water-raising contrivances and Syrian devices of this kind.

Among the manuals on old technology, the most useful and detailed study carried out before the 20th century is the work by Forest de Belidor, which includes large detailed drawings. It was overtaken in the 1950s by R. J. Forbes' work, although neither he nor Lynn White differentiate between geared and ungeared wheels. More recently the manual written by Thorkild Schiøler in the 1970s has been particularly useful for classification of the structures and for numerous impressive drawings done by the author. A modern study of water
technology is in the book edited by Örjan Wikander.\textsuperscript{8} It highlights the archaeological and written evidence for hydraulic works according to the results of four decades of historical research and offers a new basis for discussion of technical progress in antiquity. Among more ancient books, that by Georg Andreas Böckler\textsuperscript{9} has been particularly valuable for providing interesting drawings which show a large variety of different shapes of wheels.

Particular attention has been accorded to manuscripts containing detailed technological descriptions of the structures as well as original drawings, like that by Philo of Byzantium\textsuperscript{10} and Vitruvius,\textsuperscript{11} who describe the function of wheels moved by the power of water, Taccola,\textsuperscript{12} whose work contains an original drawing of a high-lift săqiya, Leonardo da Vinci,\textsuperscript{13} who describes four water-raising contrivances without right-angle gears, and Francesco di Giorgio Martini,\textsuperscript{14} who also shows various water-raising machines particularly interesting for their singular composition and different methods of construction.

Valuable for a large number of imaginative drawings of water-wheels are the 16\textsuperscript{th} to 18\textsuperscript{th} century architectural treatises, like those by Agostino Ramelli,\textsuperscript{15}

\begin{thebibliography}{9}
\bibitem{8} Wikander 2000.
\bibitem{9} Böckler 1673. This book was first published in 1661.
\bibitem{10} Hagia Sophia 3713 (Philon's water-lifting machine, folio 84r), kept in the Süleymaniyê U. Kütüphanesi of Istanbul. A French translation is to be found in Carra de Vaux 1903.
\bibitem{11} Cesariano 1521. The De Architectura by Vitruvius (1st century B.C.) was acknowledged in 1414 as the original kept in Montecassino abbey (Italy). The first printed publication in Italian, done by Cesare Cesariano in 1521, contains the best drawings from the Vitruvian originals. The English translation was done in 1960 by M.H. Morgan.
\bibitem{12} The Taccola's work is the Ms Palatino 766, kept in the Biblioteca Nazionale of Florence.
\bibitem{13} Codice Atlantico, preserved in the Biblioteca Ambrosiana of Milan.
\bibitem{14} The Trattato di Architettura by Francesco di Giorgio Martini is kept in the Ms S.IV in the Biblioteca Comunale of Siena, Ms II.1.141 in the Biblioteca Nazionale of Florence, Ms 148 in the Biblioteca Reale of Turin and Ms 361 in the Biblioteca Medicea Laurenziana of Florence.
\bibitem{15} Ramelli 1588.
\end{thebibliography}
Vittorio Zonca, Francesco Veranzio and Jacob Leupold which show how the mechanism of water-wheels, which has remained intact over the centuries, can be combined successfully with many shapes.

Among the books on water-wheels built in Islamic countries, especially useful in connection with the Syrian structures are the valuable work by Joseph Townsend, the studies by G. S. Colin, by Laïla Ménassa and Pierre Laferrière, and many others listed in the bibliography. In particular, Townsend noted an amazing relationship between the Spanish wheels and the ruins of a construction in Aleppo. Particularly remarkable for the comprehension of the Islamic technology in the Syrian devices are the studies conducted by A.Y. Hassan and Donald Hill in the 1970s and 1980s.

Many travellers have been attracted by Syria. Impressed by the beauty of the landscape characterized by the water-wheels around ۀمّة, they wrote of their amazement in front of these water structures. Among the recent travel books, the Barrès report has been one of the most impressive. Although Barrès did not provide much detailed information on individual water structures, he expressed a clear awareness of the importance and beauty of these monuments. He remarked that:

“...Jour et nuit, les grandes roues hydrauliques, quelques-unes de dimension colossale, à la fois ingénieuse et barbares, compliquées et primitives, font monter l’eau sans arrêt

16 Zonca 1607.
17 Veranzio 1615.
18 Leupold 1724.
19 Townsend 1791.
20 Colin 1932; Colin 1933.
21 Ménassa et Laferrière 1975.
22 As will be pointed out in Chapter Four, the construction Townsend refers to is most probably the water-wheel on the Quwayq river which existed in Aleppo until 1902.
Particular attention has also been accorded to Arab literature. A very important contribution to the understanding of Arab technology is provided by al-Jazari, whose work concentrates on the artistic aspect of the illustrations and is considered one of the most important contributions to medieval technology. For the mathematical precision of the wheel design, the work by al-Ansārī is particularly interesting. He considers water-lifting one of ten sciences derived from geometry. The Arabic translation of the first manuscript by Philo of Byzantium, mentioned above, has been fundamental in the comprehension of the origin of the wheels. Several manuscripts on Islamic technology include material on the water-wheels; among these the studies by the Banū Mūsā brothers, al-Murādī, Būzjānī and Taqī al-Dīn are especially valuable because they focus on the technical function of the water-wheels. In addition, medieval Arabic travel books, like those by Ibn Jubayr, Yāqūt, al-Dimashqī and Ibn Batṭūṭa describe vividly the emotions aroused by the extraordinary landscapes created by the presence of this amazing architecture on the Orontes.

24 There are 15 different copies of al-Jazari’s manuscript (1206). The earliest illustrated copy is the Ms Ahmet 3472, dating from 1206, now preserved in the Topkapi Palace at Istanbul, while in the Bodleian Library three significant illustrated copies are Ms. Greaves 27 dated 1341, Ms. Marsh 669 and Ms. Fraser Or 186 dating from 1486.
25 al-Ansārī (dec. 1348) is cited by Hajji Khalīfa (d. 1657) whose work was translated into Latin by Gustavus Flügel in Lexicon bibliographicum (Hajji Khalīfa 1835).
26 Ibn Jubayr 1952.
27 Yāqūt 1867.
28 al-Dimashqī 1874.
29 Ibn Batṭūṭa 1853, 141-143.
Not much has been written about the architecture of Syrian water-wheels and the development of their forms. However, we have to pay tribute to the Danish architect Ejnar Fugmann who, in the 1930s, took part in an archaeological mission at Apamea directed by J. P. Riis. Fugmann started studying the Orontes installations, but could not conclude his studies.\textsuperscript{30} The recent works by A. Zaqzûq\textsuperscript{31} and Delpech\textsuperscript{32} have also contributed to the knowledge of the Orontes water-wheels. However these writers are undoubtedly better trained to appreciate the technical and socio-economic achievements than the artistic qualities of these structures.

The material is divided into three main parts which include six nave chapters.

The first, which corresponds to Chapter Two, concerns the historical and structural aspects of water-wheels, providing the necessary foundation for the understanding and interpretation of visual material. This part also includes the analysis of the sources relating to the origin and development of water-wheels.

The second part deals with Syrian water-wheels and includes Chapters Three, Four, Five and Seven. Chapter Three contains an analysis of sources relating to the origin of Syrian water-wheels and the following two chapters provide an architectural analysis of these structures, focusing on the most significant examples and classifying them primarily by examining their shapes and by studying the way in which the structures draw water. This part contains the main findings of the field-work. A survey of the installations on the Orontes

\textsuperscript{30}Ejnar Fugmann did the drawing of one of the great wheels of Hamâ which has been published in Schiöler's work (Schiöler 1973, 8).

\textsuperscript{31}Zaqzouq 1990.

\textsuperscript{32}Delpech \textit{et al.} 1997.
river is included in Chapter Seven. A map indicating the sites visited where whole or parts of installations still exist is included at the end of the thesis (in Volume Two).

The third part, which corresponds to Chapter Six, deals with the development of modern systems of irrigation and their relationship with the traditional hydraulic norias and the possible re-evaluation of these ancient devices.

An architectural “Illustrated Glossary” of the most frequent terminology adopted throughout the text appears after the final chapter (“Conclusion”).

It is hoped that this thesis will contribute to the knowledge and study of water architecture in Syria by documenting the importance of the old water-structures and that it will provide new means for understanding these installations.
CHAPTER TWO

OPEN FORMS OF WATER ARCHITECTURE:
THE WATER-WHEELS
Technical and historical aspects

1. STRUCTURAL AND FUNCTIONAL CHARACTERISTICS

1.1. THE PROBLEM OF TERMINOLOGY

The system for raising water through a wooden wheel is better known as “noria” or “sāqiya”. The word noria derives from the Arabic word nā‘ūra (pl. nawā‘īr) which means “the means to irrigate which works by water and produces a sound” due to the particular sound which the wheel generates.33

The terms utilized by various authors to indicate different types of water-wheels often do not correspond. Up to the 19th century, water-wheels with pots moved by the force of the river were called Persian wheels, referring to the type most frequent in Persia.34 Forbes,35 Hassan and Hill36 call a wheel with pots moved by the force of the river noria and the wheel with pots moved by men or animals sāqiya. According to Needham and Ling37 the word sāqiya indicates the vertical hanging of an endless chain of pots and the word noria refers to a wheel

33 Steiger 1932, 287.
34 Ewbank 1842, 115. Already J. W. Gent, speaking about water-wheels used to raise water for irrigation, wrote that “...The most considerable and universal is the Persian wheel, much used in Persia, from whence it hath its name, where they say there are two or three hundred in a river...”.
35 Forbes 1956.
36 Hassan & Hill 1986.
37 Needham & Ling 1965.
with pots around its rim. Schiøler\textsuperscript{38} considers both \textit{noria} and \textit{sāqiya} machines moved by the power of animals, differing in the shape of the shaft, and he calls a wheel moved by the current of the river \textit{hydraulic noria}, while \textit{treadwheel} is a machine turned by the tread of one or two labourers. In the terminology utilized by Smith,\textsuperscript{39} a \textit{sāqiya} is simply a chain with buckets moved by man, while a \textit{noria} is a wheel moved by water. More recently, Oleson\textsuperscript{40} has simply used the word \textit{wheel with compartmented body} to indicate the Vitruvian tympanum, which corresponds to the treadwheel, while for \textit{wheel with compartmented rim} he means the wheel driven by water-power.

In addition, in some geographical areas where a number of different types of these structures are used, as in Northern Egypt, people use a generic term to cover them all. In Spain the term \textit{noria} is used both for water-driven wheels and animal-powered wheels. Caro Baroja\textsuperscript{41} uses two terms: \textit{la rueda de corriente}, to indicate a wheel moved by river power, and \textit{la noria de sangre}, to indicate a wheel moved by animals. In Syria, the term \textit{gharrāf} is used for geared wheels, while the typology of the great wheels at Ḥāma is termed \textit{noria}, or, more correctly, the classical form, \textit{nāʿura}. This term, on the other hand, is unknown in Egypt, although Europeans use the Spanish form, \textit{noria}, when referring to the Egyptian \textit{sāqiya}. In the vicinity of Aleppo, the \textit{dulāb}, a word of Persian origin (\textit{dol-āb}), which is well known in Egypt, Sudan and Iraq, is used to indicate animal-powered wheels. On the other hand the word \textit{dūlāb} is used in Morocco to

\textsuperscript{38} Schiøler 1973.
\textsuperscript{39} Smith 1978.
\textsuperscript{40} Oleson 2000 (b).
\textsuperscript{41} Baroja 1954.
indicate water-wheels with compartments on the rim moved by the current of the river. 42

Although the terminology of this machine is still not clearly defined, water-wheels are primarily divided into three types: machines moved by the power of animals, men or by water itself. In addition, for every group there are sub-classifications to indicate the different types of wheels. 43 The terminology that has been adopted here is close to that used by Schiøler, 44 which seems to be the most exhaustive.

1.2. THE TYPOLOGY

1.2.1 GENERAL CHARACTERISTICS

In general terms the system is composed of two main parts. The first includes one or more wheels, made of wood: the second is the aqueduct, made of masonry. The former is mobile, the latter is fixed. The installation always includes a vertical wheel which is placed beside the aqueduct, on the banks of a stream or partially inserted underground and, depending on the type, it can also include one or more horizontal wheels. 45 The vertical wheel turns because of the river current or the power of animals or men. Water is raised by the wheel and poured into the channel along the top of the aqueduct. The force of gravity moves the water

42 Colin 1933, 156.
43 Up to the 9th century machines to raise water were not classified, despite detailed descriptions given by Philon and Vitruvius. Only with Ya`qubi (d. 891) were machines first classified into two groups: the group powered by animals or men and the group powered by the perpetual flow of the river.
45 A detailed description of the types of water-wheels is given in the following paragraphs.
downwards into the cistern or irrigation channels. The wood employed to make
the wheels has to be durable and flexible.46

There are many advantages of this kind of water-wheel: it has a simple
mechanism and assembly, it is a clean technology for the environment and it has
easy, low-cost maintenance requirements. Since water-wheels operate
continuously, they typically require periodic partial restoration of the worn wood.
The disadvantage is that part of the water is wasted when it pours into the tank
(Fig.1).

1.2.2. MACHINES MOVED BY ANIMALS

These machines correspond to the sāqiya and noria. They indicate the type of
installation which raises water from streams or from underground to irrigate fields
and gardens or to supply water for small structures. They are composed of a
machine moved by the power of animals which turn a horizontal cog-wheel made
of wood, which then turns a vertical wheel with cogs.47 The latter transmits the
rotation to the main wheel of the structure, that is a vertical wheel partially
submerged into the water or inserted into a well (Fig. 2).

Around the rim of the main wheel there are some containers which fill up
when they reach the water. These containers consist of pots or buckets attached
with knots, at regular intervals, to a chain which runs around the wheel (Figs. 2, 3,

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46 Many types of wood can be employed, depending on local availability. For example, in Egypt
the trees used are acacia and tamarind (Menassa & Laferrière 1975, 11, 29), in Syria, mulberry,
poplar, apricot and elm are the best woods employed (information about the type of wood has
been provided by the “Department of the norias” at Ḥamā in 2004). In East Asia, the numerous
bamboo plantations provide an excellent material for water-wheels because it is easy to split and
yet strong.

47 These machines always turn right to left, due to “a natural predisposition of men to use the right
hand” (Bay 1916, 82). In fact the man incites the animal to move by using his right hand for
beating the back of the beast, which is obliged to run to the left.
4 and 5). Instead of a chain with pots, the wheel may be replaced by one which has some compartments on the rim, i.e. boxes with rectangular openings (Figs. 1 and 6). Water raised is poured into a tank. From the tank water passes directly into the distribution channels to irrigate fields and gardens.

These machines can be differentiated by the arrangement of cogs of the horizontal wheel, which can be parallel (Fig. 7) or radial (Fig. 8) to the pivot. They are also differentiated by the position and size of the horizontal axle which connects the two vertical wheels.

Noria

The installation is a “noria” if the vertical cog-wheel and the wheel with pots, or compartments, are situated in the same cavity, because they are connected to each other by a short axle (Figs. 6 and 7).

The Maghrib was characterized by norias with the horizontal wheel with parallel cogs and the vertical wheel with pots, like the examples found in Spain at Ibiza, Portugal at Loures and Morocco near Rabat. In Syria, norias with the horizontal wheel with parallel cogs and the vertical wheel with a bucket chain were found at Ma’arrat al-Nu’mân, on the road from Ḥamā to Aleppo (Fig. 10), and norias with the horizontal wheel with radial cogs and the vertical wheel with pots were found at Salḥīn, North Aleppo (Fig. 11).

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48 Norias also existed in Sicily, although today they are no longer in existence. In fact C. Baroja reminds us of the use of dialect words in Sicily to indicate the noria (Baroja 1954, 53). In fact in the dialect forms there are the words ‘a ndum, used at Siracusa, and ‘nora, used at Modica (Steiger 1932, 287).
49 This vertical wheel which supports a chain with pots is also called “potgarland”. See also the “Illustrated glossary” included in this volume.
50 At Ma’arrat al-Nu’mân and Salḥīn there were a large number of norias. In the 1970s some ruins were found (Schioler 1973), but they are no longer in existence.
Sāqiya

The installation is a “sāqiya” if the vertical cog-wheel and the wheel with pots (or compartments) are connected by a long axle and are inserted in two different cavities. The horizontal axle can be underground or elevated (Fig. 9). Sāqiyas were particularly frequent in Egypt, where there are still some examples in working order. Sāqiyas with the horizontal axle close to the ground and the horizontal wheel with parallel cogs existed between Baghdad and Babylon.\(^{51}\) Sāqiyas with an underground horizontal axle, a horizontal wheel with radial cogs and a pot garland (Fig. 2) were found in Egypt, at al-Mi’timdiyya near Cairo, while at al-Fayyūm there were sāqiyas with a vertical compartmented wheel.\(^{52}\) An example of sāqiya with an elevated shaft and a vertical bucket-chain (Fig. 9) is that found at Formia, in Italy.

1.2.3. MACHINES MOVED BY WATER

This type is that of the “hydraulic noria” which raises water using the power of the river and has been employed to irrigate fields or to supply water for bigger structures,\(^{53}\) owing to the great power provided by the river. Hydraulic norias are employed where the level of the river is considerably lower than the level of the river’s banks. Consequently they are necessary in order to raise the water to the banks. This is the type widespread in Syria on the Orontes river, but it still exists today in other parts of the Mediterranean basin, like Iraq, Turkey, Spain,

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\(^{52}\) Lewis 2000, 645.

\(^{53}\) Many hydraulic norias, such as those in Syria, are employed to supply water for mosques, hammams, khans, houses and public fountains, in addition to gardens and fields.
Morocco, Portugal, in East Asia and Central America where its technology has not changed (Figs. 13-25). Hydraulic norias existing in East Asia and some examples in Central America are also still in use for irrigation.

The base of the wheel is submerged in the river and turns because of the current. Water is carried to the top of the wheel, through compartments or pots placed on the periphery of the rim, and is poured into the channel on the top of the aqueduct, and is directed to irrigate fields and gardens. Where the wheel is submerged into the river, the power of water presses on the paddles placed on the periphery of the wheel causing the rotation of the wheel itself and the filling of the compartments.

To move the wheel continuously, it is necessary that the river flows at a constant speed. In some cases, like in Syria, a dam, which is made of masonry (Figs. 26 and 27), bars the river to maintain an initial sufficient level of water and to increase the speed of water in the main channel.

A brick or stone structure, rectangular or triangular in shape, supports one of the ends of the wheel axle. In large installations, like the Syrian ones, this wall, which is called “triangle” because of its shape, has steps on both sides to allow access to the nave of the wheel for maintenance. The other end of the axle is placed on the sill of the aperture of the so-called “tower”, that is the fronton of the aqueduct. At the bottom, the wheel rotates between the wall supporting the wheel axle and the façade of the tower.

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54 Hydraulic norias in the Mediterranean countries were in use until the first half of the 20th century. Today they are no longer in use for irrigation. In some cases, like in Syria and Portugal, they are kept in working order. They were also in use in the Arabic peninsula around Medina in the 19th century, when this typology was evidenced by Richard Burton (Burton 1893, 399-400).
The rotation velocity of the wheel increases with the velocity of the flowing water. Thus, the most appropriate locations to install the water-wheel are in places where the water stream is narrowest, thereby causing the water velocity to reach the highest safe value.

The size of the wheel is variable, depending on the quantity of water to raise. The diameter can range between a few metres and more than 20 metres, as in some Syrian and Chinese examples.\(^5^5\)

Although they look rustic, they show a sophisticated construction, characterized by a simple assembly and maintenance. The main structure of the wheels consists of two pairs of continuous parallel beams perpendicular to each other. They are the main spokes of the structure and are pivoted around a central axle supported at each end by stone walls. The secondary beams stabilise the structure. They can be radial (like in France, Turkey, parts of Spain and in the Syrian examples on the Orontes) (Fig. 28), oblique (like in some parts of Spain, Morocco and Portugal) (Fig. 29) and perpendicular to the main beams (like in the Iraqi and Syrian examples on the Euphrates and Khabūr rivers) (Fig. 30). The introduction of secondary beams to the structure of the wheel, creates geometric designs of the wheel itself, which show different regional variations (Fig. 144).

It is relevant to note that, in the Syrian hydraulic norias on the Orontes, which will be analysed in detail in Chapter Four, the secondary beams do not have a precise radiality, because they start from four centres.\(^5^6\)

\(^{55}\) For the analysis of the typology of the hydraulic norias on the Orontes see Chapter Four.

\(^{56}\) For a discussion of the structure of the Syrian wheels, see paragraph “Variations in wheel construction and design” in Chapter Four.
Hydraulic noria with pots

There are two types of hydraulic noria: the type with pots (Fig. 29) and the type with compartments (Fig. 28). The wheel with pots is composed of a wooden cross-braced rim. A large number of pots are lashed to the outer rim. The main three elements of hydraulic norias with pots are the same in the compartmented examples (the stone supports, the wheel and the irrigation channels which run inland to water the fields).

The hydraulic noria with pots characterized the Syrian and Iraqi banks of the Euphrates (Fig. 14), the Syrian banks of the Khabūr and the Nabāo river in Portugal (Fig. 16), and was also in use in Central Asia on the Oxus river around Khīwa. Although this typology, according to Crooke, does not seem to be used in Persia, J. W. Gent said that in Persia, in the second half of the 17th century, there were two or three hundred in a river.

The hydraulic noria with pots was also used in Central America, where it was introduced by Spain during the Spanish colonisation in the early 16th century, in particular in the northern Mexican states of Aguascalientes, Zacatecas, San Louis Potosí, in the Yucatan Peninsula and in Jamaica (Figs. 19 and 24). The

57 Northedge et al. 1988, 21; Charles 1939, 48-49.
58 Dias 1986.
59 Olufsen 1911, 192-193.
60 Crooke 1906, 282.
61 Gent 1675, 18. In addition Gent gave a detailed description of these machines, emphasizing their advantages: "...the most advantageous way of raising water in great quantity to any altitude within the diameter of the wheel...by this Persian wheel placed in the river in the nearest place to the highest part of the land you intend to overflow, therewith may a very great quantity of water raised..."
62 West and Augelli 1989, 260. There are installations still in existence, as the wheel at Jalcomulco on the Huiztilapan river, or that at Falmouth in Jamaica. Some of them are no longer in operation, due to the high cost of maintenance for moving the wheels (i.e. dissembling and reassembling the machines) during the annual floods (Doolittle 1990).
connections between Spanish and Central America examples are particularly
evident in the Jamaican example (Fig. 19) which has a wheel design very similar
to the medieval Spanish hydraulic noria at Murcia (Fig. 31). Both are
characterized by a radial position of the secondary beams.

A unique typology of hydraulic noria with pots is that still in use in South
China in the Guanxi region, on the Linxi river, in West China in the Gansu region
on the Yellow river, in Burma, Indonesia, Cambodia, Thailand and Sri
Lanka (Figs. 18, 20, 21 and 22). They are characterised by a very light and
flexible structure made of bamboo. The wheel consists of two parallel rims
connected to each other by parallel bars and with numerous radial spokes. Pots
are also made of bamboo and are tied to the rims.

Compartmented hydraulic noria

The second type of hydraulic noria is the compartmented hydraulic noria, which
is characteristic and widespread in Syria in the Orontes valley (Fig. 13). This type
has the wheel which is similar to the pot-wheels, but in place of the pots there are
compartments. Some compartmented hydraulic norias are still to be found in
Egypt (Fig. 15) and in Spain (Fig. 25), like the example at Cordoba, although in
the Islamic period they were numerous. In Morocco only one large example at
Fès has survived (Fig. 17). Until the 1960s there were also six installations in

64 Delpech et al. 1997, 237.
65 Thorkild Schiøler www.experimentarium.dk.
66 Baroja 1954, 120-122.
67 Colin 1933, 156.
Turkey, near Antakya, along the Orontes river. They may have had the same typology as the Syrian hydraulic norias still located in the Ḥamā area.

The typology of hydraulic noria also includes the so-called “overshot wheel”, where water passes over it and is caught in buckets attached to the circumference, and turns the wheel by its weight. This kind, suitable for sluggish rivers in flat lands, was not used for irrigation, but mainly employed for grinding corn. This type is no longer in use. Remains of overshot water-wheels, dating back to the 2nd century A.D., have been found at Barbegal, in France (Fig. 40).

There is another type of wheel which can be classed as a type of hydraulic noria, being moved by water power. It has an evident connection with the chain with pots of machines with a gear. In fact, the machine is assembled with a metal chain without end which carries a sequence of buckets hanging vertically from its stoking wheel to the water. The buckets are upside-down on the descending chain, while on the ascending chain the buckets are full of water. The power of the water moves a cylindrical structure which enables the rotation of the chain through two wheels connected by a horizontal axle (Fig. 32).

1.2.4. MACHINES MOVED BY MEN

The third type of water-wheel is moved by man power. It is known as a “treadwheel”. The wheel is cylindrical in shape, like a drum, crossed by a horizontal axle. Inside, the drum is divided into eight, or more, internal sectors, emphasized outside by the spokes of the wheel. Every sector is opened on the periphery by a hole to allow water to enter the wheel. These containers fill with

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68 Baroja 1954, 70; Weulersse 1946, 257.
69 Weulersse 1946, 256.
water at the bottom. Through internal channels, water arrives at the middle of the wheel, and flows out to an external channel through a hole (Fig. 33). In other cases water arrives at the top of the wheel and is poured into an elevated channel (Fig. 34). Instead of cavity segments (fig. 33), the treadwheel can have square buckets on the rim (Fig. 34). Treadwheels can be turned by treading on steps inside the wheel (Fig. 33), or from above (Fig. 34 and 35).

This type is no longer in use. Treadwheels were once used for irrigation, for feeding Roman baths or draining mines, like in Portugal\(^ {70}\) and Spain,\(^ {71}\) where remains of this type have been found. Other remains of treadwheels have been found in Italy at Ostia Antica\(^ {72}\) (Fig. 35) and in Wales at Dolaucothi (Fig. 36).\(^ {73}\)

A particular type of treadwheel turned by means of both hands and feet was found in northern India in Rajputana, Kathiwar and Punjab.\(^ {74}\) This device consists of a series of vessels bound sideways on a wheel, and was used to raise water from a shallow well, usually for irrigation purposes (Fig. 37).

2. FORMATION AND EVOLUTION OF WATER-WHEELS

2.1. THE PROBLEM OF THE ORIGIN

Water-wheels are very ancient. It is difficult to assert for certain when the water-wheel originated, and which was the first typology to be constructed. Although different hypotheses have been advanced, they are not supported by enough

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\(^ {70}\) Díaz 1986, 37-57.  
\(^ {71}\) Schiöler 1973, 39.  
\(^ {72}\) Schiöler 1973, 136.  
\(^ {73}\) Bonn 1966, 122.  
\(^ {74}\) Mukery 1907, 142.
convincing evidence. According to the hypothesis put forward by J. Needham and W. Ling, the machine to raise water could have originated in India in the fourth century B.C. and it may have spread to the West by the first century.\textsuperscript{75} Reynolds' theory is that water-powered wheels originated in the Near East around 200 B.C.\textsuperscript{76} This hypothesis has also been asserted by Forbes who has suggested that it is more likely that the most primitive water-wheel was horizontal and originated in the mountain region of the Ancient Near East, and spread to the East and the West before the first century B.C., although it was suitable for moving mill-stones, and hence was used for small scale corn-grinding, its vertical shaft would have made it unsuitable for moving waterhoist.\textsuperscript{77} Curwen claims that the water-wheel may have originated in China before the 1\textsuperscript{st} century B.C. and that it was a hydraulic noria. From China it could have entered the Mediterranean world in the 1\textsuperscript{st} century B.C.\textsuperscript{78} According to Oleson it is possible that both the compartmented wheel and the paddle-wheel drive (i.e. wheels moved by the power of water, or "hydraulic norias") were invented together in the late fourth century B.C. in Egypt, for water-lifting, while the säqiya gear drive appeared a century or two later, again in Egypt.\textsuperscript{79} In fact the Nile, and some of the more active irrigation channels fed by it, provided an excellent location for this type of device. G. S. Colin's thesis is that water-wheels have an Aramaean origin, due to the supposed Aramaic etymology of the Arabic word \textit{nā'ūra}. In addition, Colin

\textsuperscript{75} Needham and Ling (Needham & Ling 1965, 361) have put forward the idea that the water-wheel originated in India owing to its wide distribution and frequency there in the past, and because certain ancient Indian texts dating from around 350 B.C. mention a machine which seems to be a noria.
\textsuperscript{76} Reynolds 1983, 14-16. Reynolds refers to the pictures of the vertical water-wheels done in late third century B.C. by Philo of Byzantium in his \textit{Pneumatica} (see note 168).
\textsuperscript{77} Forbes 1965, v. 2, 41.
\textsuperscript{78} Curwen 1944, 145. This hypothesis is not convincing enough. According to Gille the earliest hydraulic wheels in China were horizontal (Gille 1954, 2).
\textsuperscript{79} Oleson 2000 (b), 236.
highlights the importance which Aramaean agricultural techniques have had in the Arab world.\textsuperscript{80} Thus it is possible to put forward the hypothesis that the water-wheel appeared during the 7\textsuperscript{th} or 6\textsuperscript{th} centuries B.C. in Mesopotamia when Aramaic gradually replaced Akkadian as the spoken and written language. But Colin does not specify which type of installation \textit{nā'ūra} refers to and no physical evidence exists for it. However, it is also possible that a water-wheel, moved by the river (i.e. a hydraulic noria), already existed in the 7\textsuperscript{th} century B.C. Evidence for this derives from the text of an Akkadian tablet dated to the neo-Assyrian period.\textsuperscript{81} In addition, the word \textit{nā'ūra} probably derives from the common Semitic noun for “river”, which appears in Akkadian as \textit{nāru},\textsuperscript{82} in Aramaic as \textit{nahrā},\textsuperscript{83} in Hebrew as \textit{nāḥār}\textsuperscript{84} and from which a denominative verb “to flow” is derived.

2.2. ANALYSIS OF SOURCES

2.2.1. TEXTUAL AND ARCHAEOLOGICAL SOURCES

To understand the probable origin and the development of the typology, an analysis of sources, including archaeological findings, literary texts and architectural treatises, has been carried out. In particular, textual and archaeological sources have shown that the earliest water-wheel might have been a sāqiya, probably originating in Egypt at least in the 3\textsuperscript{rd} century B.C. The

\textsuperscript{80} Colin 1932, 43.
\textsuperscript{81} Johns 1901, 18-20. For a detailed discussion of this document, see the following paragraph “Analysis of sources”.
\textsuperscript{82} Gelb et al. 1964, 368.
\textsuperscript{83} Sokoloff 2002, 734.
\textsuperscript{84} Koehler & Baumgartner 1958, 599-600.
treadwheel probably appeared in Egypt in the 1st century B.C. As far as the hydraulic noria is concerned, the sources analysed here have shown that it existed in the 1st century B.C., with certainty, but the place is still uncertain. However there is the possibility that it already existed in the 7th century B.C., although, as will be analysed later, this is based on the interpretation of one cuneiform text.

Sāqiya and noria

The earliest water-wheel was a sāqiya, for which there is much archaeological evidence, e.g. sāqiyas found at Fayyūm dating from the 3rd century B.C. In the Peri Alexandreias by Callixenus there is the first mention of the existence of a sāqiya used at Alexandria during the reign of Ptolemy IVth (221-205 B.C.). Subsequently, a fresco from the 2nd century B.C., representing a compartmented sāqiya, has been found in Alexandria. It shows two oxen yoked to opposite ends of a beam walking around a circular brick platform, turning the vertical drive shaft of a sāqiya (Fig. 38). Of the same period is a Greek papyrus found at Fayyūm which mentions a μηχανή (sāqiya) as a means of irrigation in Ptolemaic Egypt. It reports the text of a “Private Letter Regarding Farm Matters” which

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85 According to the definition of the types of water-wheel in the paragraph on typology, the so-called shādīf has not been considered as a water-wheel. It was a counter-weighted bailiing bucket which appeared in Near Eastern art as early as the 3rd millennium B.C. (Forbes 1965, v. 2, 17). Sources related to irrigation systems in antiquity often do not make clear which kind of typology they refer to. In some cases it can be understood as a shādīf or as a water-wheel. In this thesis, sources analysed relate to a clear existence of water-wheels.

86 As will be seen, this interpretation does not provide convincing evidence for the existence of hydraulic norias in the 7th century B.C..

87 In the paragraph on sources, owing to the minor architectural difference between sāqiya and noria (explained in the paragraph “Machines moved by animals”), the term sāqiya is intended as a water-wheel moved by an animal, therefore including the wheel with a short shaft (i.e. the noria) and the wheel with a long shaft (i.e. the sāqiya itself).

88 Oleson 1984, 209-212.

89 Callixenus Rhodius 1849, 55-56.

90 The fresco is in the Graeco-Roman Museum in Alexandria.
mentions that Harpaesis and his three assistants were to be hired to work a water-wheel for irrigation:

...to...edes greetings and good health. Since we are in need of four workmen for the irrigation of the fields please send Harpaesis to us with three others who are skilled in working the water-wheel [ὁρναύζων]. They will receive their pay daily. Goodbye.91

Plutarch, around 110 A.D., mentioned a compartmented wheel in *Numa*. It could be a sāqiya because Plutarch calls it an “Egyptian wheel”,92 but does not describe it:

“...The way in which the worshippers turn around is said to be in imitation of the rotation of the universe...unless, by Zeus, the changing of position speaks in riddles and teaches something like the Egyptian wheels: how nothing human remains the same...”93

The following evidence of the existence of an animal-powered machine appears in 113 A.D. and is in the *Greek papyrus 1177* where there is mention of ὄχλα-ταί (“ox-drivers”) involved with irrigation:

“...Account of revenues and expenditure for the water supply...Wages for ox-drivers at the water tower Alsos, with 2 machines and 6 ox-drivers...for the days from 18th to 30th of the same month Pauni, total 13 days, on one of which only one machine with 3 ox-drivers was used, while on the remaining 12 days, 6 ox-drivers were used, making 72 (total) ox-drivers...”94

91 It is the papyrus n. 5 preserved in Cornell University. English translation in Westermann & Kraemer 1926, 42-43.
92 Most historical sources analysed, here mention that water-wheels in Egypt refer, in fact, to animal-powered wheels.
93 Plutarch, 1914, XIV, 8-9
94 This papyrus is preserved in the British Library in London. The English translation is in Kenyon 1973, 180-190. Two previous Greek papyri, i.e. the *Greek papyrus 1120* (dating from 5 B.C. and preserved in Ägyptische Urkunden aus den Museen in Berlin) and the *Greek papyrus 131* (dating
Sulpicius Severus in his *Dialogi*, dated to the early fifth century A.D., describes this machine in the Egyptian desert:

“...I had with me as a guide one of the monks who knew the area well...There was a well...He (the monk) possessed an ox whose only task was to raise water by driving a machine fitted with wheels [*machina rotalis*]...”

95

The majority of archaeological remains of săqiya are in Egypt and Nubia starting from the 3rd century A.D. with the examples found at Armant and Kôm Auşim (Egypt) and at Faras, Wadī al-Sebwa and Adīndān (Nubia). 96

The remains of a săqiya with an elevated shaft have been found at Formia, in Italy, and most probably date back to the late Roman period (Fig. 105). 97

During the patriarchate of the Coptic Church of Alexandria in the 8th and 9th century, the evidence points to the existence of water-wheels at Alexandria, between 744 and 768:

“...At that time Marwān [prince of Egypt] was informed that his enemies, the Khorassanians, had arrived at Al-Faramā, he sent troops in boats that they might burn all the boats that they found on the river; and this purpose they carried out. And he despatched other troops by land, with orders to burn the cities and villages and vineyards and water-wheels and every thing that they could find...”

98

from 79 A.D. preserved in London in the British Library), mention a water-lifting machine which may refer to a săqiya (Schöler 1973, 125-126). However this has not been supported by convincing evidence and the hypothesis that they could refer to a shādīf is still the most probable (Johnson 1936, 135-136, 201).

100 Oleson 1984, 210, 218 and 279.
101 Schöler 1973, 125.
102 *History of the Patriarchs* 1910, 169.
and between 830 and 849:

“...Who would not be filled with admiration on hearing of the virtues of this holy and blessed father, Abba Joseph? Listen now to yet another wonder, my friends, concerning this father. There was at Alexandria a man who was one of the Chalcedonian heretics; and he was very rich, and possessed water-wheels. So when he went out one day to take recreation in one of his vineyards outside Alexandria, he saw a broken water-wheel, and asked for a carpenter. Now there was an old man, a priest, who was also a carpenter. So the Chalcedonian said to him: "Wilt thou come now with me, that thou mayest mend the water-wheel for me?" But the priest replied: "Today is the Great Friday; and I can do no work today, because it is the day on which the Word of God, the Saviour of the World, was crucified." Then that cursed heretic opened his cavilling mouth in answer, and blasphemed God the Word, saying what must not be recorded. So the aged priest reproved him, and went away ...”

Among legal documents dated 850 included in the papyrus coming from al-Ushmūnain, there is evidence of a noria on the canal of Hōr:

“...Verily ye have asked and petitioned that I lease unto you three faddāns of black clay-earth appertaining to the land which was in the hands of Pa-Hōr, belonging to the land watered by the noria to the south of the canal of Hōr, that thou mayest sow it...”

Al-Balādhurī, in 892, mentioned water-wheels “driven by camels” in Baṣra:

“...In Baṣra, on one of the farms founded by Muḥammad ibn Sulaymān, there were water tanks (ḥawel), which were filled by camel-driven waterwheels (dawlāb)...”

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99 History of the Patriarchs 1915, 516.
100 The village of Hōr is situated to the east of Dair Abū Fāna on the right side of the Bahr Yūsuf.
101 Grohmann 1936, 43.
102 al-Balādhurī 1916, 98.
Particularly surprising have been the small water-wheel shaped objects found in the Monastery of Saint Macarius at Cairo dating from the 12th century.103

"...the superior [of the Monastery] acknowledged that there were no vessels “except a silver chalice, and a silver paten, and a silk veil which we hang before the sanctuary at the time of Mass.” These objects, he stated, were gifts from Christians, and had the donors’ names inscribed upon them. They were then produced and taken to Cairo, where they were shown to El Kāmil; among them was a “water-wheel of crystal of wonderful workmanship and a network of pearls...”104

From the following period we have a miniature from Baghdād illustrating a sāqiya moved by two animals. The vertical paddle wheel resembles a spiral. Some details of the machine are clearly represented, like the two stone pillars which support a transversal beam which passes over the structure and rests on the vertical axle, and the boundary wall which surrounds the circular track on which the animals move. Water raised by the vertical paddle wheel and poured into a circular tank is represented in the foreground of the illustration (Fig. 38a).105 Sāqiyas dating from the 12th century also existed at Trapani, in Sicily.106

103 The typology of the objects mentioned is not specified, but it is possible that it is a sāqiya, owing to their proliferation in Egypt.
104 White 1932, 382.
105 The miniature is on folio 69 verso of Ms. Arabe 5847 (al-Maqāmāt) by al-Ḥarīrī, illustrated by al-Wasiti. It is preserved in the Bibliothèque Nationale of Paris.
106 Sorre 1948, 245.
Treadwheel

The treadwheel may have appeared later in Egypt. It is first mentioned in Roman literary texts from the 1st century B.C. In fact in 48 B.C. Hirtius, in De Bello Alexandrino, mentions a treadwheel used by Caesar to raise water from the sea, when the Roman army was passing through Alexandria:

"...When all the sewers had been blocked up, and after all the sections of the city held by Caesar had been isolated, he began to raise a great deal of water from the sea by means of water-wheels [rotae] and machinery [machinationes]. He poured this out steadily from elevated places on Caesar's position..."108

These wheels were often used as a means of torture for prisoners. Prisoners were condemned to lift water for mines or bathing establishments, as described by Strabo in 18 B.C., Suetonius in late 1st century A.D. and Artemidorus in the 2nd century A.D.:

"...There is a ridge running from the fort down to the Nile along which wheels and dowels bring water up from the river: 150 prisoners are kept busy at the work..."109

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107 It should be noted that the device composed only of a chain with pots moved by men, which can constitute a particular type of treadwheel, probably originated in Babylon (Iraq) in the 6th century B.C. as evidenced by the remains of three bucket-chains housed in three shafts (Oleson 1984, 188). According to Koldewey (Koldewey 1914, 92) the findings belonged to the foundations of the Hanging Gardens of Babylon and were part of a water-lifting system. This system of raising water was also used in Italy, where two examples have survived, at Cosa and Pompei. The former was built around 150-125 B.C., the latter at the end of the second century B.C. (Oleson 1984, 242-8). The hypothesis that the 7th century B.C. system for raising water mentioned in Deuteronomy 11: 10-11 was a treadwheel (Schäfer 1918, 140-141) is not supported by convincing evidence and could refer to a shedd, as Forbes asserted (Forbes 1965, 17).

108 Hirtius 1675, 357-358.

109 Strabo 1829, XVII 1.30.
"...He [Tiberius] also held Livia's will to be invalid and within a short time began to prosecute all her friends and intimate associates...; one of these, a man of equestrian rank, was even condemned to the water wheel [antlia] ..."110

"...I know a man who dreamt that only his feet were walking while the rest of his body remained stationary. But, despite the movement, his feet did not advance even slightly. He was subsequently condemned to the hold of a ship. For it is the lot of those who bale a ship that they take strides, as if they are walking, but they always remain in the same spot. Another man, moreover, dreamt that water flowed from under his feet. Afterwards, this man, who was a criminal, was also condemned to the ship's hold and it was in this way that water flowed from under his feet.111

Tertullian in 210 A.D. mentions a compartmented wheel in De Anima as a means for draining the mines:

"...For even those who will be reincarnated as asses and mules to be punished by toil and servitude, how will they congratulate themselves on the mild labour of the mill and the water-wheel, when they recollect the mines, and the convict gangs, and the public works, and the very prisons, although there was more leisure there!..."112

The earliest remains of treadwheels date back to the 2nd century A.D.. They were wheels with a compartmented rim used for feeding Roman baths, like at Ostia (Fig. 35), Pompei and Herculaneum, or for draining mine shafts like in Rumania at Zlatna, in Spain at Rio Tinto, in Portugal at Santo Domingo and in Wales at Dolaucothi (Fig. 36). The wheels for draining mine shafts were very similar to each other. Their probable Roman origin is particularly evidenced by the fact that

111 Artemidorus 1975, 1, 40.
112 Tertullian 1988, 33, 7.
their design is based on a geometric construction similar to that in the Pantheon. This is particularly evident in the wheel which existed at Rio Tinto, in Spain. As Kurent has noted, this wheel and the Pantheon have a similar division of the circumference. In addition the opening at the top of the Pantheon’s dome and the wooden centres of the wheel are in the same proportion to the whole (Fig. 58).  

While most water-wheel chambers in Roman mines have now been lost, some remains survive in Roman bath buildings. The Bath of Mithras found at Ostia, in Italy (Fig. 35), consisted of two wheel-rooms side by side. A wheel with compartmented rim lifted water from a subterranean reservoir to a catch basin at ground level. This water flowed into the second wheel-room, in which a similar wheel was installed, lifting the water to an elevated cistern which fed the baths. As the picture shows, large and heavy wheels of this type may have required the efforts of two treaders at the same time.

*Hydraulic noria*

As will be discussed later, sources have shown with certainty that the hydraulic noria already existed in the 1st century B.C.. However, it is opportune first to consider the possibility that it originated in ancient Mesopotamia, at least in the 7th century B.C. This theory is based on interpretations of some Akkadian words referring to scripts in a tablet from the district of Harrān, in ancient Mesopotamia,

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Kurent 1967, 31-32. In both cases the diameter of 7 modules permits the division of its circumference into 28 smaller modules, and the centre in both cases is theoretically one fifth of the diameter.
in the Neo-Assyrian period.114 This tablet analyses objects dealing with the irrigation apparatus: “carriage”, “plough”, “door”, “water-hoist”, “irrigator”, “knobs” (karru) and “dowels” (sikkatu) of knobs. Laessøe115 has noted that these terms, together with the general picture of the context in which the irrigation apparatus is listed, would seem to render the assumption likely that a sluice is described. The knobs, attached by their dowels in holes at either side of the sluice, may have held in place the lock-gate which could be moved up and down, thus forming a valve by means of which the flow could be stopped or regulated, like the main channel of the hydraulic norias of the Syrian typology. However this description could also correspond to an underground channel similar to a qanāt or a fujjarā.116 Laessøe says that when the description of the sluice is preceded by an account of an irrigation apparatus, there seems reason to believe that this is an undershot water-wheel, powered by the water as it flows through the passage under the lock gates behind which it was stored up. On the other hand, as the right column of the tablet is not preserved, the Akkadian terms for the sluice and the water-wheel cannot be established with certainty.117 According to Laessøe, the equivalent of the logogram “giš.a.DUL + DU” referred to this system has been translated by different Akkadian words, whose meaning refers to a hydraulic

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114 Johns 1901, 18-20. This is the tablet N. 5 belonging to the cuneiform tablets, dating from the 7th century B.C., referring to a census of the district round Harrān. It corresponds to the area north of the Euprates, after it takes its great bend to the east and before it begins to turn south, and between that river and the Tigris (Johnson 1901, 7).
115 Laessøe 1953, 23-24
116 Laessøe himself underlines that a sluice which fits this description at one time existed in the Wādī Bastura tunnel of Sennacherib (Laessøe 1951, 29-30).
117 Laessøe 1953, 23.
noria. These words have been interpreted as *sūru* according to Ungnad,\(^{118}\) *dalbu* according to Smith,\(^{119}\) and *šiknu* according to Thureau-Dangin.\(^{120}\)

Thureau-Dangin has also noted that the *šiknu* is also mentioned in two letters from Hammurabi,\(^{121}\) both of which are addressed to Šamaš-hāšir, governor of Larsa.\(^{122}\) The *šiknu* is mentioned as a machine whose function is raising the water level, a sort of amplifier in the canalisation system whereby a current was produced:

"A la bouche du canal Ugdimša allez, puis, si les eaux sont diminuées, si les eaux n’atteignent pas leur champ à loyer, à la bouche du canal Ugdimša installez-leur un courant d’eau.\(^{123}\) Si les eaux qui maintenant dans le canal Ugdimša montent, ne sont pas en petite quantité, pour inonder. Leur champ à loyer sont suffisantes, aucune machine (*šiknu*) à la bouche du canal Ugdimša n’installez." \(^{124}\)

In the other letter we can read:

"If there is water at Larsa and Ur, build no dam (*šiknu*) at the mouth of the rivers, of which I have spoken to thee. If there be not water at Larsa and Ur, build dams at the mouth of the rivers, of which I have spoken to thee, that there may be water indeed at Larsa [and at] Ur." \(^{125}\)

\(^{118}\) Ungnad, 1935, 139.

\(^{119}\) Smith 1924,81. This identification was upheld hypothetically by the excavators of Ur in connection with a structure found in the sanctuary E-gipar. The structure corresponds to a well in the corner of the courtyard of the sanctuary. (Gadd 1929, 238-239). This identification and Smith’s definition of *dalbu* as “an object which moves quickly, for which a wall was necessary”, leads us to think that the structure could not necessarily have been a hydraulic noria, but a chain with pots.

\(^{120}\) Thureau-Dangin 1924, 32.

\(^{121}\) Laesses 1953, 24.

\(^{122}\) Hammurabi lived in the 19th century B.C.

\(^{123}\) According to Thureau-Dangin “courant d’eau” means a machine which raises water and produces current (Thureau-Dangin 1924, 32).

\(^{124}\) This letter is published by Thureau-Dangin as n. 39 and translated by him (Thureau-Dangin 1924, 32).

\(^{125}\) This letter is published and translated by Driver (Driver 1924, 2 and Pl. II) as No. 2.
However, if a machine which raises water and produces a current was installed, the šiknu, as Lassøe has noted, must have required a power source and cannot be identified with the hydraulic noria; but the letters are couched in terms too general to allow any conclusion as to the exact structure. In addition, the fact that in the latest official Chicago Assyrian dictionary the translation for šiknu, as well as for suru and dalbu, reports meanings not related to types of irrigation system, makes the old hypothesis that these words refer to water-wheels less convincing.

Certainly the hydraulic noria existed in the 1st century B.C., but the exact place is still uncertain. The earliest evidence for this is in literary texts. Lucretius, who lived in the first half of the 1st century B.C., first mentions the water-wheel in De rerum naturae, comparing the rotation of a water-driven compartmented wheel to the perpetual motion of the celestial spheres, which turn incessantly:

"as we see rivers turn wheels, with their scoops [rotae atque austra]."

In addition, an early imperial inscription found at Mantinea in honour of Euphrosynos and Epigonos, dating from the second half of the 1st century B.C., mentions the rebuilding of "compartmented wheels turned by water" at the gymnasion to provide water for drinking:

"...and when the wheel below the gymnasion burned down, he graciously gave bricks prepared for his own use [for its repair], preferring the adornment of the city to benefit at home...."

126 Thureau-Dangin 1924, 32, note 3.
127 Laessøe 1953, 24.
128 Gelb et al. 1964, 27-28 and 52-56, (dalbu); 366-370 (suru); 436-439 (šiknu).
129 Lucretius 1963, V, 193.
An epigram by Antipater of Thessalonika, who lived in the 1st century B.C., suggests the use of water-wheels:

"...Cease from grinding, ye women who toil at the mill; sleep late, even if crowing cocks announce the dawn. For Demeter has ordered the Nymphs to perform the work of your hands, and they, leaping down on the top of the wheel, turn its axle, which with its revolving spokes, turns the heavy concave Nysarian millstones. We taste again the joys of the primitive life, learning to feast on the products of Demeter without labor ..."131

In 75 B.C. Pliny, in his Natural History, mentioned the wheels turned by water in use in a greater part of Italy:

"...Major pars Italici nudo utitur pilo, rotes etiam, quas aqua versat, obiter et mola..."132

Strabo refers to a hydraulic machine found in Pontus in the palace of Mithridates, King of Pontus, at the time of his defeat by Pompei in 65 B.C.. It is possible, as Usher has asserted, that this machine may have been constructed almost a hundred years before this event, during the construction of the palace,133 but it is not possible to assert which typology is referred to.

The earliest physical evidence of a vertical water-wheel is the lava impression found in 1908 at Venafro, near Pompei, in Italy, on the Tuliverno river (Fig.

130 Oleson 1984, 102.
131 Paton 1950, 418.
133 Usher 1970, 165.
This dates the wheel at least to the early 1st century A.D., before the 79 A.D. eruption of Vesuvius.

From the 2nd century A.D. there is also the earliest evidence of overshot wheels, found at Barbegal in France, employed for the grinding of corn (Fig. 40). They consist of eight pairs of 16 parallel wheels. Water arrived from an aqueduct which was supplied by two rivers. The installation was built along the hill slope.

A drawing of a vertical water-wheel, showing a scene from the life of Jesus, belongs to the 11th century *Hortus Deliciarum* by Herrad von Landsberg (Fig. 41). Because the scene is related to the 1st century A.D., this may be further confirmation that a vertical water-wheel was already in use at that time.\(^{135}\)

In the 3rd century *Mosella* by Ausonius there is a mention of a water-wheel moved by a tributary of the Mosella river:

> "...Te rapidus Celbis, te marmore clarus Eubris Festinant famulis quam primum adlambere lymphis Nobilibus Celbis celebratus piscibus, ille, Praecepti torquens cerealisa saxa rotatu, Stridentesque trahens per levia marmora serras, Audit perpetuos ripa ex utraque tumultus..."\(^{136}\)

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\(^{134}\) In the National Museum at Naples there is a wooden reconstruction of this wheel. According to F. M. Feldhaus the small size of the wheel (which had a diameter of 93 centimetres) suggests that it was part of an automaton and not from working mill (Feldhaus 1936, 472). However L. Iacono considers this wheel belonging to a hydraulic noria because of the two millstones found nearby which probably connected to the wheel (Iacono 1938, 851).

\(^{135}\) The original manuscript was damaged by a fire in 1870. We possess a reproduction of the original drawings done by the abess Herrad von Landsberg in the monastery of Hohenburg from 1159 to 1180. The scene represents “Two women grinding wheat” which belongs to a series of scenes of a prayer of Jesus on the necessity of achieving salvation and the uncertainty of the last hour: “...Two women will be grinding the mill; one will be taken by death, the other will be left at her work...”. The miniature shows a vertical paddle wheel whose horizontal shaft has a gear wheel which makes the millstone turn.

\(^{136}\) Ausonius 1888, V, 362. Among the manuscripts where the text or part of it is included, the 15th century Codex Laurentianus LI, 13, preserved in the Biblioteca Medicea Laurenziana in Florence, is that which holds the complete work of Ausonius.
In the early 3rd century A.D. Heliogabalus mentions the existence of water-wheels in Syria, which watered the gardens at Apamea:

...Parasitos ad rotam aquariam ligabat, et cum vertigine sub aquas mittebat, rurusque in summum revolvebat...".  

"...rotarum aquariarum fiue aquilegarum, ut vocat Tertullianus, mentio apud Vitruvium, rei rustice scriptores & saepius apud iurisconsultos..."138

Also dating from the 3rd century A.D. there is the earliest visual reference to an overshot water-wheel depicted in a mural painting in the Roman catacombs of Saint Agnes (Fig. 42).139

A mosaic in the imperial palace in Constantinople (Fig. 43), dating from the 5th century A.D., depicts a big water-wheel beside a rectangular building, which could be a hydraulic noria lifting water to the top floor of a house.140

Dating from the reign of the emperor Marcianus (455-457) is the "overshot" hydraulic noria found at Athens, discovered in excavations in the Agora in 1933.141

137 *Scriptores historiae Augustae* 1603, v. 1, 163-164.
138 *Scriptores historiae Augustae* 1603, v. 2, 432. The mention of Tertullian refers, probably, to treadwheels (see note 112).
139 It is the Mains cemetery near St. Agnes in Rome (Hill 1993, 110; Testini 1966, 163). The overshot water-wheel was first described by Philo in 250 B.C. The picture in the Roman catacomb has been described by A. Profumo in the *Nuovo bulletin di archeologia cristiana* in 1917 (Marucchi 1917, 108), who refers this scene to the job of the dead person, but has never been published.
140 It is also possible that the mosaic represents a water-mill for grinding, owing to the small dimension of the building beside the wheel (Dulière 1974, 36). This mosaic was uncovered during the excavations done by the Walker Trust of St. Andrews University at the beginning of the 20th century.
141 Parsons 1936, 88.
The floor mosaic dating from 469 found at Apamea represents a hydraulic noria of the same type as those actually existing on the banks of the Orontes (Fig. 44).\(^{142}\)

In the 6th century *Vita Patrum* by Gregory of Tours a water-wheel is mentioned at Loches on the Anger river where the stream, being confined in a race between poles, and provided with sluices made of great stones gathered from round about, caused the wheel to revolve with great rapidity:

"...Ursus abbas hæc ageret, ac fraters molam manu vertentes triticum ad vistus necessarium, comminuerent, pro labore fratres visum est ei molendinum in ipso Angeris fluvii alveo stabilire; desisisque per flumen palis aggregates lapidum magnorum acervis exclusas fecit, atque aquam canale collegit, cujus impetus fabricæ rotam in magna volubilitate vertere fecit..."\(^{143}\)

In the late 8th century al-Zubaydī wrote the *Tāj al-'arūs* where he mentions hydraulic norias on the Euphrates and Orontes.\(^{144}\)

From al-Ṭayyib in 885 to al-Dimashqī in 1327, Arab travellers, whose accounts refer to the hydraulic norias on the banks of the Orontes, speak about their spectacular aspects. A detailed analysis of the sources referring to Syrian hydraulic norias is in Chapter Three.

\(^{142}\) However, as will be discussed later, the wheel shown in the mosaic and the existing Orontes wheels have some differences. A discussion related to this mosaic is in Chapter Three.

\(^{143}\) St. Gregory 1623, *XVIII*.

\(^{144}\) al-Zubaydī (no date), 65.
Apart from the Syrian water-wheels (which will be discussed later), the Arab travellers describe hydraulic norias seen in many areas of the Mediterranean basin during the Middle Ages.

In the 9th century, in al-Balādhūrī’s History of the Arab conquests, there is a reference to the use of hydraulic norias on the Tigris.

Installations on the Iraqi side of the Euphrates are mentioned by the geographer Ibn Rustah in the 10th century who speaks about hydraulic norias in the Iraqi area of the Nahrawān canal east of Baghdad. Subsequently, in the 12th century, Ibn al-Jawzī mentions the existence of hydraulic norias on the Tigris north of Mosul, in the western part of Bādūrayā west of Baghdad and in the northern part of the Anbar area on the Euphrates.

In his Ahsān al-taqāṣīm fi ma’rīfat al-aqālim, written between 985 and 990, al-Muqaddāsī first mentions hydraulic norias in Iran, along the Masrūqān river at Ahwāz:

"...we can see, on the river, many hydraulic wheels moved by water, called norias, from which water flows towards the basins and the gardens, due to its elevated canalisations"

The earliest evidence of the existence of a water-wheel in Spain dates back to the 10th century. According to the Historia de los reyes de al-Andalus y de Marruecos written in 1306 by the Muslim historian ibn Idhārī al-Mahrākushī, in the 10th century, i.e. during the reign of ‘Abd al-Rahmān III, an enormous hydraulic noria

145 al-Balādhūrī 1866, 363.
146 Ibn Rustah 1967, 163.
was built at Cordoba:

"...Abd al-Rahman III built a house at Cordoba, in the middle of gardens watered by the Guadalquivir river by hydraulic machines. The building was called after al-Ma’mun’s palace at Toledo, i.e. the munyat al-nā’ura and was the caliph’s favourite residence during the first part of his reign..."\(^{149}\)

The wheel mentioned above is the big wheel of the hydraulic noria called *Albolafia* (Fig. 25).

In 1154 there is the following mention of Spanish hydraulic norias by al-Idrīsī, who describes the big hydraulic noria of Toledo where there were also smaller wheels for irrigation (Figs. 45 and 46):

"...In the Tago river there is a strange bridge, built with only one arch, under which water flows rapidly and moves a noria (*nā’ura*) by which water goes up to 90 *codos*\(^{150}\) and, passing over the arch, goes into the city..."\(^{151}\)

According to al-Maqqarī, in the 11th century, on the Guadalquivir river, there was a great quantity of hydraulic norias.\(^ {152}\)

Al-Ḥimyarī, in the same period, talks about the hydraulic norias at Murcia and Almeria:

"...for irrigations the wheels called *dawlab* and *saniya* are used at Murcia...Water which arrives at Almeria arrives through hydraulic wheels..."\(^ {153}\)

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\(^{149}\) Levi Provençal 1932, 224-225.

\(^{150}\) Because 1 *codos* corresponds to 47 cm. (Torres Balbas 1940, 198), the 90 *codos* which al-Idrīsī speaks of correspond to 42.30 m.

\(^{151}\) al-Idrīsī 1866, 288.

\(^{152}\) al-Maqqarī 1861, 307.

\(^{153}\) Torres Balbas 1942, 463-464.
In the early 12th century also al-Saqundi remembers the sound of these wheels at Murcia:

"...en la orillas de lo rio hay tantos jardines de ramas ondulantes, tantas norias que cantan notas musicales, tantos pajaros gorjeadores y flores alineadas, como habras oido..."\textsuperscript{154}

Dating from the early 12th century is an interesting capital in a church of Vezelay, in France. Carved into it are two figures using a water-wheel; clearly visible is the hopper and what appears to be a lantern cog-wheel rather schematically rendered (Fig. 47).\textsuperscript{155}

There is also mention of hydraulic norias in Sicily in the 12th century, located on the Oreto river around Palermo, according to the description produced by the 12th century historian Falcando:

"...there (near Palermo) there were speedy norias [rotae volubilis obsequio descendentibus] through which water is raised from the spring and the cisterns are filled up and through them (the norias) water flows towards many sides ..."\textsuperscript{156}

In the 12th century \textit{L’Image du Monde}, a treatise of natural philosophy, by Gautier of Metz, there is a representation of a city with a water-wheel on the outskirts.\textsuperscript{157}

In the \textit{Hadith Bayād wa Riyād}, dating from the 13th century, there is also a representation of a Spanish hydraulic compartmented noria showing elaborated geometric motifs (Fig. 48).\textsuperscript{158}

\textsuperscript{154} al-Saqundi 1934, 115.
\textsuperscript{155} Gille 1954, 5.
\textsuperscript{156} Sorre 1948, 244.
\textsuperscript{157} The representation is in the folio 71 verso on Ms Heleian 334, preserved in the British Library in London.
A 13th-century compartmented hydraulic noria also appears in the *Liber Anselmi qui dicitur Apologeticum* (Fig. 49) and in the *Rentier d'Audenarde*. As Ibn al-Khaṭīb asserted in his *Iḥāta fī akhbār Gharnāṭa*, the first hydraulic noria in Morocco was built at Fez in the second half of the 13th century for the sultan Ya’qūb al-Mansūr by Ibn al-Ḥājj, a Muslim Spaniard from Marsiglia. He specified that the wheel had a large diameter, carried a great quantity of water and had numerous compartments called *akwāb*. He also indicated that the Spaniards introduced this typology to Morocco. Colin believes that the hydraulic noria arrived in Morocco from Spain, where it had been imported from Syria, maybe before 1085, when the Christians arrived in Spain.

In the 14th century Ibn Baṭṭūṭa reports the existence of water-wheels at Ḥamā, near Amasia and Samarqand, while Ibn Jubayr mentions the machines at Ḥamā and at Dunaysir between the Tigris and the Euphrates, as well as the wheels at ‘Āna along the Euphrates some of which are still in existence (Fig. 14).

### 2.2.2. ARCHITECTURAL TREATISES

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158 The miniature is in the folio 19 recto on Ms Ar 368 preserved in the Vatican Library.
159 The miniature is in the folio 10 recto on Ms Cottonian Cleopatra C XI, preserved in the British Library in London.
160 The manuscript dates from about 1270 and is preserved in the Bibliothèque royale in Bruxelles.
163 Ibn Baṭṭūṭa 1853, vol 1, 141-143.
164 Ibn Baṭṭūṭa 1853, vol 2, 292.
165 Ibn Baṭṭūṭa 1853, vol 3, 52.
166 Ibn Jubayr 1952, 250.
Treatises of architecture first dealt with water-wheels, have allowed the comprehension of their construction, assembly and function, by describing a simple and effective technology which has not changed for centuries.

The first treatise which deals with water-wheels is the Kitāb fi’l-hiyal al-ruḥāniyya wa-majāniqa ("The book of pneumatic devices and of hydraulic machines"), which is the Arabic version of the Greek treatise *Pneumatica* by Philo of Byzantium from the 3rd century B.C. He mentions an undershot water-wheel applied to a bucket-chain moved by the current of the river (Figs. 50 and 51) and a hydraulic compartmented noria (Figs. 52 and 53) of the overshot type. In fact Philo was one of the inventors of pneumatics, as Yaʿqūbī cited in 891:

"...Philo is one of the inventors of the pneumatics...Devices that are driven by water without being driven [by man or beast]..."  

But, it is possible, as Drachmann and Schiøler have asserted, that the water-wheels described in Philo’s manuscript are not original, but later Arabic additions. In fact the original Greek manuscript is lost and there is a gap of two centuries between Philo and the next reference to a bucket-chain and to a hydraulic compartmented noria in the architectural description done by Vitruvius.

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167 Philo of Byzantium 1974 (61, 223-5; 65, 230-3). The best Arabic copies of *Pneumatica* are in the 14th century manuscripts Hagia Sophia 2755 (folio 145 verso) and Hagia Sophia 3713 (folio 77 verso and 84 recto) preserved in the Suleymaniye U. Kütüphanesi at Istanbul (Carra de Vaux 1903, 39). The Hagia Sophia Ms also includes drawings by an unknown author representing wheels for raising water (Schiøler 1973, Fig. 53, p. 75). An interesting Italian translation from the Latin version is on folios 1-8 of the 15th century Ms 34113 preserved in the British Library in London. This manuscript, in addition to the copies from the Philo manuscript, also includes many drawings of several types of water-wheel which have evident connections with those drawn by Francesco di Giorgio Martini, i.e. a similar architectural context and similar shape of the machines.

168 Folios 77 recto and 84 verso of the Ms 3713 show the original drawings of a bucket-chain (folio 77r) and a compartmented overshot water-wheel (folio 84v) of which a reconstruction was attempted by Carra de Vaux in 1903 (Carra de Vaux 1903, 202 and 210).

169 al-Yaʿqūbī 1883, 135.

in about 27 B.C. in *De Architectura*.\(^ {171}\) Vitruvius in the 10\(^{th}\) book of *De Architectura* gave a detailed description of all vertical wheels and how they work, that is the treadwheels, which he calls *tympanum*,\(^ {172}\) the hydraulic noria with compartments “which turns when the faces of their floatboards are struck by the current of the river”,\(^ {173}\) the wheel with compartments moved by man and utilized in place of the tympanum “when [the water] has to be raised higher”,\(^ {174}\) and the bucket-wheels (Figs. 54-57).

A chain of pots has been used to raise water from wells. It can raise water from the river, but, compared to the hydraulic wheel, it also has the advantage of raising water from underground. There is much confusion in the description of the chain of pots by ancient authors, who refer to the chain with pots as a wheel indiscriminately. After the early explicit mention by Philo of the bucket-chain to raise water\(^ {175}\), Vitruvius describes the bucket-chain:

> “if we need to raise water, on the axle of the wheel we have to put an iron chain hanging over the water, and link some copper pots to the chain. Pots go on the axle, turn upside down and spill on the tank water which they have raised”.\(^ {176}\)

\(^ {171}\) On the other hand the shape of the hydraulic noria, with perfectly radial spokes and numerous paddles between the two external rims, drawn by Philo (Fig. 52 and the reconstruction in Fig. 53), is more similar to the Roman representations, like that in the *Maius* catacomb in Rome (Fig. 42) than Arab drawings, like that by the Banu Musa (Fig. 59), or that in the anonymous 12\(^{th}\) century military manuscript (Fig. 62).

\(^ {172}\) *Vitruvius 1960, X 4.1..* The Vitruvian *tympanum* corresponds to the “treadwheel” (Schipler 1973) or to the “wheel with compartmented body” (Oleson 2000).

\(^ {173}\) *Vitruvius 1960, X 5.1..* This wheel corresponds to the “hydraulic noria” (Schisler 1973).

The best preserved drawings of Vitruvian descriptions are those done by fra Giocondo in 1511 and Cesare Cesariano in 1521.

\(^ {174}\) *Vitruvius 1960, X 4.3.* This wheel corresponds to the wheel with compartmented rim (Oleson 2000).

\(^ {175}\) *Philo of Byzantium 1974, 65, 233-5, 239, 289.*

\(^ {176}\) *Vitruvius 1960, X, 9.* So it is likely that this machine has derived from the bucket-wheel mentioned by Philon.
and makes the same distinction clear:

"...But if a supply is required at still greater heights, a double iron chain [duplex ferrea catena] will be set up, wound around the axle of the same sort of wheel (the treadwheel with compartmented rim) and allowed to hang down to the lowest level with bronze buckets suspended from it. The chain will carry the buckets to the top, and as they are borne over the wheel they will necessarily turn over and pour out into a reservoir what they have raised..."\(^{177}\) (Fig. 57).

Hero of Alexandria in the 1\(^{st}\) century B.C. also tried to make a distinction between a bucket-chain and a wheel for raising water:

"...The pumping (to move water) is carried out, if the spot is much lower, by means of a bucket-wheel, or the so-called "bucket-chain". But if it is only a little lower, it is done by means either of water-dowels or wheels with compartmented bodies, mounted side by side..."\(^{178}\)

The principle of axial flow was known in the Islamic world since the 9\(^{th}\) century when it was attested by the Banu Mūsā brothers who, in their Kitāb al-ḥiyal ("Book of Ingenious Devices") written in Baghdad in about 850, described a horizontal wheel placed in one of their fountains and driven from below by a number of vertical jets of water (Figs. 59 and 60).\(^{179}\)

It is also valuable to note the encyclopaedia of science Mafāṭīḥ al-ʿulūm ("Key to the Sciences"), written in 975 to 977 by al-Khwārizmī, which deals

\(^{177}\) Vitruvius 1960, X, 4.4.
\(^{178}\) Hero of Alexandria 1971, VI, 200.
\(^{179}\) There are two manuscripts of the Kitāb al-ḥiyal: one is Ms ar. 317 in the Vatican Library, the other is in two parts, the Codex Gotha 1348 in the Universitäts-Bibliothek at Gotha and the Ms von Ahlwardt 5562 at Berlin.
with the hydraulic components used in Fine Technology.\(^{\text{180}}\)

The *Inbāt al-Miyah al-khafīyya* ("The extraction of hidden waters") was written in about 1019 by the Persian scientist al-Kharaji. This treatise describes the instruments used by master well diggers and *qanāt* builders, methods of detecting sources of water and instructions for the excavation of underground conduits.\(^{\text{181}}\)

In the early 11\(^{\text{th}}\) century al-Murādī wrote a treatise on automata and water-clocks called *Kitāb al-asrār fi nata'īj al-aʃkār*, which is the first technical work from Spain. We have a 13\(^{\text{th}}\)-century treatise which is probably a faithful copy of the original \(^{\text{182}}\) and includes the *Kitāb al-dawālīb wa al-arḥa wa al-dawā'īs* ("Treatise on the hydraulic wheels, mills and presses") which deals with overshot wheels. It shows how a vertical water-wheel supplies power to move a system of gearing (Fig. 61).\(^{\text{183}}\)

In the 11\(^{\text{th}}\) century Iraqi treatise by Būzjānī titled *Kitāb al-Hāwī li'l-a'māl al-sultaṇīyya wa rusūm al-ḥisāb al-dīwānīyya* ("The containing book of the Sultanic Works and the Royal Cabinet Charges"), the performances of the various types of water-raising machines in use in Iraq are compared, including the three types of water-wheel.\(^{\text{184}}\)

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\(^{\text{180}}\) al-Khwārizmī 1895.

\(^{\text{181}}\) The Arab manuscript written by al-Kharaji is the oldest existent manuscript on groundwater science. It has been translated into Persian. A technical paper by Nadji and Voight published in English in 1972 reviews al-Kharaji's work.

\(^{\text{182}}\) The wheel represented on the left of the drawing could be a hydraulic noria (Hassan & Hill 1986, 62) which runs a system of cog-wheels (on the right in the drawing) by the power of the water.

\(^{\text{183}}\) This manuscript is the Ms. OR 152 preserved in Florence at the Biblioteca Medicea Laurenziana. On folio 49 recto there is a phrase which indicates the date of conclusion of the manuscript, i.e. 1266 A.D.

\(^{\text{184}}\) Cahen 1949-51, 117; Samarran 1972, 26-29. It is the Ms. Arabe 2462 preserved in the Bibliothèque Nationale of Paris.
We also possess a chapter on water-wheels which is included in a military manuscript called *Al-hiyal fi'l-hurūb wa fath al-madā'in wa hifz al-durūb* ("Stratagems in wars, the conquest of towns and the guarding of passes"), whose author is unknown. According to Hassan and Hill the chapter on water-wheels must have been copied from an original treatise, at the present unknown, written between the ninth and twelfth centuries. In this work there are descriptions of different types of wheels which are not to raise water for irrigation, but perpetual motion machines without an external source of energy. In particular there is a drawing of a machine whose radial pipes correspond to the spokes of the wheel and are partially filled with mercury whose weight causes the rotation of the device. The pipes are not radial towards the centre but are inclined at an angle to the radial direction. As the wheel turns, the mercury moves inside the pipes from one end to the other, which exerts a turning force (Fig. 62). There is also a drawing of a machine with mallets hinged to the rim of the wheel. Some of the mallets are ascending and others are descending; there is an overbalance on one side compared with the other, and the wheel is supposed to turn indefinitely. A third type of machine represents a wheel where the arms are multi-jointed and as the wheel turns they close up and wrap themselves around the wheel on one side and extend themselves on the other, thus creating an imbalance which is supposed to cause rotation.

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183 It is the Ms. K.T.S. Müzesi A 3469, preserved in the Topkapu Serai Müzesi Kütüphanesi at Istanbul. Other manuscripts of this treatise are in Leiden (Ms. Orientalis 499 or CCO 1414, Bibliothek der Rijksuniversiteit) and Rabat.
186 Hassan & Hill 1986, 70.
187 Hassan & Hill 1986, 71.
In the same period Ibn al-'Awwām, in his *Kitāb al-Fīlāḥa* ("Book of Agriculture"), although it is not a technical treatise, first gave suggestions for improving the performance of a sāqiya and noria, like increasing the number of cogs in small vertical cog-wheels and increasing the diameter of the horizontal wheel, and making a hole at the base of the pots in order to avoid the risk of torsional movement and consequent collision when the pots are submerged in the water. In this way the pots can empty when the wheel stops turning, enabling the cord to last a long time. He also suggested building the big wheel of thick heavy wood to allow the machine to turn more easily.

The description and the function of a sāqiya were first given by al-Jazarī in the early 13th century. He produced detailed partially three-dimensional drawings describing the function of the wheel for raising water, enabling future craftsmen to construct the machine. Al-Jazarī described in detail how geared water-wheels work. The most significant drawing, copied in different manuscripts, allows us to understand the use of the sāqiya clearly (Fig. 63). Al-Jazarī’s description of the cog-wheel, which is fundamental to the entire machine, is highly innovative. In addition to the study of some types of cog-wheels (Fig. 64), he described the main cog-wheel, which is that on which the

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188 Ibn al-‘Awwām 1878, 146-147.
189 Al-Jazarī did detailed drawings and descriptions of the water-wheels which are in the chapter *Wheels which turn by themselves* of the *Al-jāmi‘ bayn al-‘ilm wa al-‘amal al-nāfi‘ fi šīnā‘at al-ḥiyāl* ("A Compendium on the Theory and Practice of the Mechanical Arts"). The original manuscript was written at the Artuqid court at which al-Jazarī was employed during the last quarter of the 12th century A.D. (Ward 1985, 69). Of the fifteen copies which survived, the earliest illustrated copy, written in 1206, was probably compiled under the supervision of al-Jazarī himself (Ward 1985, 80). It the Ms. K.T.S. A 3472, now in the Topkapi Palace at Istanbul where there is also the second best copy, the Ms K.T.S. Müzesi H 414. The best preserved copies of his manuscripts are the Ms. K.T.S. Müzesi A 3350 and A 3461 (in the Topkapi Palace) and the Ms Marsh 669, Ms Fraser OR 186 and Greaves 27 (in the Bodleian Library at Oxford) of which D. Hill first did a translation in 1974.
190 Previously architectural treatises did not describe the cog-wheels which have been a pivotal element for all geared wheels. Subsequently they became a object of deep reflection in the Renaissance treatises like those by Leonardo and Francesco di Giorgio Martini.
pot-chain turns and discharges water in the channel.\textsuperscript{191} Although the *sāqiya* is simple and has a unique function, al-Jazārī presented different drawings of sāqiyas, showing many typologies, such as the double symmetrical pot-chain to raise more water (Fig. 65), the wheel with spoon-paddles (Figs. 63 and 66) (which seems to be a reference to that described by Philo of Byzantium (Fig. 51)) or the wheel with rectangular paddles (Fig. 67). The wheel with rectangular paddles belongs to a sophisticated piston pump, and the sāqiya with an elevated shaft (Fig. 63) corresponds to the machine still existing in Damascus. Of both piston pump and sāqiya at Damascus a detailed description is in Chapter Five.

In the *Libro del Relogio*, i.e. the 5\textsuperscript{th} book of the *Libros del Saber de Astronomia*, prepared in 1277 under the direction of Alfonso X of Castile, there are two detailed descriptions of hydraulic norias: the first is characterised by an intersection of crosses, the second by two concentric rims intersected by numerous radial spokes (Fig. 144).\textsuperscript{192}

Dating from around 1430 is the German anonymous *Codex latinus monacensis, part 1*,\textsuperscript{193} a technical manuscript dealing mainly with military and mechanical technology. It includes detailed descriptions and drawings of water systems, i.e. devices that were part of the water-distribution system in many medieval cities, systems including canals and fountains, and a German hydraulic noria with pots (Fig. 68) which feeds water to a fountain through a line of pipes. This drawing shows the sort of system that many fifteenth-century cities in

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\textsuperscript{191} The structure with a similar function is shown by Philo of Byzantium in *Pneumatica*, where he describes the bucket-chain.

\textsuperscript{192} *Libros del saber de Astronomia* 1866.

\textsuperscript{193} The manuscript was written by the so-called “Anonymous of the Hussite wars” because it refers to the conflicts between Catholic and Hussite Bohemians. It is the Ms Clm 197-1 and is preserved in Monaco in the Bibliotheca Regia Monacensis.
Germany used to supply water to their public fountains and how the hydraulic noria was known and employed in northern Europe as well as the Mediterranean basin.\textsuperscript{194}

Between 1427 and 1433 Taccola (the nickname of Jacopo Mariano) described the sāqiya in his Liber Tertius de ingeneis ac edifitiis non usitatis.\textsuperscript{195} He first provided a new drawing of a sāqiya, showing the possibility of a unique horizontal axle, as the rotating arm and the load-bearing part of the structure (Figs. 69 and 70). He was also innovative because he showed the “first evidence of the compound crank and connecting-rod in Italy”, as L. White has asserted.\textsuperscript{196}

Subsequently Francesco di Giorgio Martini wrote the best architectural treatise which deals with water-wheels.\textsuperscript{197} He did numerous drawings which describe the function of machines with gears and without. The drawings show a unique composition and different ways of building water wheels. He used a new way to represent them, like a packaged unit. As L. Reti has said, his drawings are “of such technical excellence as only to be surpassed by Leonardo”\textsuperscript{198} (Figs. 71-76).

The function of cog-wheels which transmit movement and the function of a hydraulic noria were explained and scientifically proved by Leonardo da
Vinci in his studies in the Codice Atlantico.\textsuperscript{199} In addition Leonardo starts to give a geometric definition of water-wheels (Figs. 77 and 78).

The drawings in the book on machines by Taqī al-Dīn done in 1551 in Damascus\textsuperscript{200} show connections to some by al-Jazarī. In particular he describes a pump very similar to that described by al-Jazarī, except that there was a scoop-wheel instead of a paddle-wheel and the connecting rods were attached to an extension of the slot-rod, not at its centre line (Fig. 79). He also describes a remarkable six-cylinder “monobloc” pump driven by a wheel with spoon paddles moved by water-power (Figs. 80-81).

In 1564 to 1569 Januelo Turriano dedicates the 11th book of his \textit{Ventiun Libros de los Ingegnos y Máquinas}\textsuperscript{201} to the study of wheels with gears and without (Figs. 82-85). Although some of his drawings seem to refer to studies by Vitruvius for the connection with the \textit{tympanum} and al-Jazarī for the connection with the cog-wheels, he drew a sāqiya, showing three types of buckets.

Subsequently, several architectural treatises were written between the 16th and 18th centuries on the subject of the water-wheel, but only a few were innovative. Most refer to Francesco di Giorgio’s drawings for the representation of an architectural context for the wheels. A particular aspect of these treatises is the illustration of the architecture of wheels often derived from the imagination of the

\begin{itemize}
\item \textsuperscript{199} Codice Atlantico, folio 26 verso, 421 verso and 706 recto.
\item \textsuperscript{200} The manuscript - \textit{Al-Turuq al-saniyya ft ’ålāt al-ruḥāniyya} (“The Sublime Methods of Spiritual machines”) - is now located in Dublin’s Chester Beatty Library (N. 5252), and was published by Hassan in 1976.
\item \textsuperscript{201} The 11th book is included in Ms 3375 in the Biblioteca Nacional de Madrid.
\end{itemize}
artist, but which shows elements from the three fundamental reference points, i.e. Vitruvius, al-Jazari and Francesco di Giorgio.\footnote{202}

Agostino Ramelli in 1588\footnote{203} described the possibility of systems of water-wheels which develop in height and a system of different hydraulic compartmented norias moved by a sequence of cog-wheels similar to those described by Francesco di Giorgio. He also shows a horizontal spoon-wheel of the type described by al-Jazari. There is an architectural structure which includes systems of wheels, but differs from those by Francesco di Giorgio in the use of a surreal axonometry instead of perspective (Figs. 86 and 87).

In the drawings done by Vittorio Zonca in 1607\footnote{204} there is an unusual typology of the säqiya which seems to be inspired by the Vitruvian tympanum, but is polygonal in shape (Fig. 88).

In 1615 Francesco Veranzio\footnote{205} presented a geometrical structure of orthogonal beams in an overshot hydraulic noria and in cog-wheels located in a sort of baldachin (Fig. 89).

In his treatise in 1673 Böckler\footnote{206} proposed more stylized solutions. In a simple and compact structure there are two levels of hydraulic compartmented norias where it is possible to note the star-shaped main wheel and an unusual cog-wheel with rounded cogs. He also shows a variation of the Vitruvian tympanum

\begin{footnotes}
\footnote{202}{The 15th century anonymous Ms 34113 mentioned above includes many drawings of several types of water-wheels which have evident and impressive connections with Giorgio Martini's style (see note 167).}
\footnote{203}{Ramelli 1588.}
\footnote{204}{Zonca 1607.}
\footnote{205}{Veranzio 1615.}
\footnote{206}{Böckler 1673.}
\end{footnotes}
connected with a bucket chain and different solutions in the shape of the beams of the wheels (Figs. 90-93).

The best treatise in the 18th century which deals with water-wheels is that by Leupold who proposed hydraulic wheels with new shapes due to the triangular and trapezoid profiles of the compartments.  

He also proposed an unusual horizontal cog-wheel, characterized by a symmetrical intersection of radial and perpendicular braces (Figs. 94-97).

It is interesting to note the suggestions given by Townsend in his travel account of Spain, although it is not an architectural treatise. After having observed Spanish hydraulic norias, he noted that part of the water ran out of the buckets and fell back into the well after it had been raised nearly to the level of the reservoir. In addition he noted that a considerable proportion of the water to be discharged was raised higher than the reservoir, and fell into it only at the moment when the bucket was at the highest point of the circle, and ready to descend. He suggested a remedy for most of these defects by leaving these square buckets open at one end, making them swing on a pivot, fixed a little above their centre of gravity, and placing the tank of the reservoir in such a position as to stop their progress while they are perpendicular, making them turn upon their pivot, and so discharge their contents.

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207 Leupold 1724.
208 Townsend 1791, 79-81.
The above-mentioned treatises show that the mechanism of water-wheels can successfully be combined with many shapes, including imaginative designs which are not to be found in existing wheels.

The treatises up to the 19th century have dealt with the technical aspects of water-wheels, but their imaginative aspects have not been considered. They have reproduced the basic mechanisms of the water-wheels, although they propose new alternative materials like steel, and often still bear the characteristic traits and style of the prototypes in the Francesco di Giorgio manuscripts, in particular the representation of an architectural context for the wheels.
CHAPTER THREE

SYRIAN WATER WHEELS IN HISTORICAL SOURCES

1. THE HYDRAULIC NORIAS

The earliest mention of a water-wheel in Syria is by the Roman emperor Heliogabalus in the early 3rd century A.D., when he remembered that a hydraulic noria watered the gardens of Apamea (Fig. 98). In fact, he describes the beautiful gardens in Apamea, with flowers and animals, then mentions the existence of water-wheels:


209 As has been pointed out, if the cuneiform scripts from Harran refer to hydraulic norias, the earliest installations could have first appeared in this area at least in the 7th century B.C. (see also pp. 64-67). Because of the lack of descriptive material, it is difficult to say if the installations were compartmented or with pots. However, they could have been hydraulic norias with pots because of the vicinity of the Harran area with the Euphrates and Khabur rivers, where hydraulic norias with pots were once numerous (see paragraph "Hydraulic norias in East Syria" in Chapter Four, pp-139-141).

210 Apamea is located on the right bank of the Orontes, 55 km northwest of Hamah. It overlooks the Ghâb plan.
...Parasitos ad rotam aquariam ligabat, et cum vertigine sub aquas mittebat, rurusque in summum revolvebat..."  

"...rotarum aquariorum fiue aquilegarum, ut vocat Tertullianus, mentio apud Vitruvium, rei rusticae scriptores & saepius apud iurisconsultos..."  

The flora which owes its existence to the river is also depicted in the 3rd Roman mosaic representing the personification of the Orontes and its tributaries. It shows an old man (the Orontes) surrounded by children (the tributaries) and by luxuriant vegetation (Fig. 99). Considering that the level of the Orontes banks is much higher than the river level, and that the only known system which was able to raise a great quantity of water to a higher level for irrigation was that of the hydraulic noria, it likely that such luxuriant vegetation was guaranteed by the use of hydraulic norias.

The archaeological excavations carried out between 1932 and 1938 by the Danish mission at Ḥamā revealed a 3rd-century Roman sanctuary. During the Arab conquest in 636, in Ḥamā the Great Mosque (al-Jāmiʿ al-Kabīr) was built on the site of the previous “Greatest Church” (al-Kanīṣat al-ʿUzmā) which was itself constructed on the site of the Roman sanctuary (Figs. 100-102). Under the level of the original pavement of the sanctuary, a system of canalisations made of terracotta was found during the excavations. According to J. P. Riis the

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211 Scriptores historiae Augustae 1603, v. 1, 163-164.  
212 Scriptores historiae Augustae 1603, v. 2, 432.  
213 The mosaics of the gardens at Apamea and of the personification of the Orontes are preserved in the National Museum of Damascus.  
214 Riis 1935, 34.  
216 Riis 1965, 15.  
217 The entrance to the Roman sanctuary would have corresponded to the entrance to the prayer room of the mosque.
construction of the canalisation would explain the existence of medieval mortar between the Roman slabs, as the pavement would have been lifted in the 12th or 13th century in order to lay the terracotta pipes.\(^{218}\)

However, we cannot exclude the possibility that a water conduit already existed in the same place to provide water to the previous church and Roman sanctuary. It is possible that the known as aqueduct al-Muḥammadīyya carried water to the sanctuary. Its remains are very close to the ancient Roman sanctuary and are perfectly orientated towards the direction of the mosque (Fig. 103), and therefore the underlying Roman sanctuary.

As the earliest sources have shown, Syrian hydraulic norias date back to at least the 3rd century A.D..

It is possible to sustain the theory that hydraulic norias first appeared in Syria during Roman times\(^{219}\) between 60/50 B.C. (the date of the first descriptions of hydraulic norias by Vitruvius and Lucretius\(^{220}\)) and the early 3rd century A.D., when Heliogabalus first identified the Orontes valley as the place where he had seen a hydraulic noria and when the Roman structures mentioned above may have existed in Ḥamā.

The oldest floor mosaic representing a hydraulic noria has been found in Apamea, and dates from 469 A.D.\(^{221}\) The mosaic, now in the New Museum at Ḥamā (Fig. 44), decorated one of the porches which crossed Apamea from north

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\(^{218}\) Riis 1965, 6 and 16.

\(^{219}\) Syria became a Roman province under general Pompey (Gnaeus Pompeus) in 64 B.C. and remained under Roman control, in the form of the Byzantine Empire until 636 A.D.

\(^{220}\) Both Vitruvius and Lucretius describe hydraulic norias without referring them to a specific place.

\(^{221}\) The date is shown in the inscription located at the northern edge of the mosaic.
to south. It represents gardens on the Orontes showing luxuriant vegetation and a hydraulic noria of the same type as those actually existing on the banks of the Orontes. There are the same concentric rims and a triangle, while it is not clearly represented if the means to raise water are compartments or pots. The radiality of the spokes, which is a typical characteristic of Roman wheels in hydraulic norias, is different from the current position of the spokes in the Orontes wheels, which, as will be shown later, could have characterized the wheels with the advent of Islam.

The oldest Arab literature concerning Syrian water-wheels refers to the hydraulic norias on the Orontes banks for their spectacular aspects. The first evidence is in the late 8th century in Muqaddimat Tāj al-'arûs min jawāhir al-qāmūs by al-Zubaydī where the author specifies that the hydraulic norias at Ḥamā were the most important among those which he had seen on the Euphrates and on the Orontes. In addition in Tayyib’s work in 885 it is written:

“...Ḥamā is a town with a stone wall, beside which there is a big stone building. The river flows and waters the gardens and drives their waterwheels (nāʿūra)...”

Subsequently Ibn Jubayr was impressed by the regular geometry and symmetry of the hydraulic norias, as he described during his travels in Syria in 1184:

“...An account of the city of Ḥamā. May God Most High defend it...To the east of the city I saw a large river that in strong course spreads out and branches, and on its banks observed water-wheels that faced each other. Along these banks are disposed gardens

222 Mayence 1933, 5.
223 Baroja 1954, 65.
224 This text, referring to the great wheels at Ḥamā, is also mentioned in Yāqūt’s work (Yāqūt 1867, 331).
that hang their branches over the water, the green leaves appearing like down on its cheeks as it flows through their shade, gliding through the line of their symmetry...”\textsuperscript{225}

Water-wheels along the Orontes are also remembered by Yāqūt in 1229:

“...On the Orontes there are several waterwheels, which raise the water so that the garden can be irrigated and pour water into the cistern of the mosque...”\textsuperscript{226}

There is also evidence of water-wheels built near Ḥamā in the 13\textsuperscript{th} century when Abu’ l-Fidā’ wrote that an Arab engineer, Ta‘āsīf, in 1244\textsuperscript{227} “built several towers in Ḥāma and a mill by the Orontes”.

“...Inter ceteros operibus fuis exsequendis adhibebat Schaichum Al-ed-dinum Kaifarum, vulgo Taafīfum dictum, geometram, in mathematicis exercitatissimum, qui plures ipsi turres Hamatae condidit, et molam fumentariam ad Orontem, et sphaeram ligneam inauratam, in qua stellas omnes, quae aut folent, aut possunt, observari, designaverat...”\textsuperscript{228}

Abu’ l-Fidā’ makes no specific mention of the construction of hydraulic norias, which, however, were already numerous on the Orontes at that time. However, the “towers” Abū’ l-Fidā’ refers to could have been the towers of some hydraulic norias. In addition he mentions that Ta‘āsīf had built mills which, as will be

\textsuperscript{225} Ibn Jubayr 1952, 252-253.
\textsuperscript{226} Yāqūt 1867, 331.
\textsuperscript{227} Ta‘āsīf, the nickname of ‘Alam al-Dīn Qaysar, was born in 1178 in Egypt where he was also educated. He also worked in Mosul, where he became famous as an architect and mathematician, but he mainly lived in Syria to serve al-Malik al-Muẓaffar during the Ayyubid reign. He was also an astronomer and engineer.
\textsuperscript{228} Abulfedæ Annææ 1792, 479. The Ta‘āsīf celestial globe, which Abū’ l-Fidā’ refers to, is the globe made of wood and gilt dating to 1225 now preserved in the Capodimonte Museum at Naples (Grabar 1967, 32; Contadini 1989, 232; Curatola 1993, 298; Germano & Nocca 2001, 154).
shown, have been traditionally connected to hydraulic norias.\textsuperscript{229} Moreover, the shape of the Orontes wheels derives from a precise geometric composition based on the intersections of star-shaped figures.

Thus, we can consider the possibility that Taʿāṣīf, an architect and astronomer who worked in Ḥamā, may have designed some hydraulic norias on the Orontes and that his studies of the stars and celestial globes may have inspired the construction of the wheels.\textsuperscript{230}

In 1321 Abu’l-Fidāʾ also gave a detailed description of the area around the “nahr Ḥamāt”, or “al-ʿĀṣi”, as he called the Orontes river, specifying the needs for hydraulic norias along the river for irrigation:

“...it (the river of Hamat) is also called “the Rebel” (Alassy) because most other rivers irrigate the lands without the use of wheels and buckets, while the Hamat river is employed for irrigation through the use of hydraulic machines...”\textsuperscript{231}

In about 1330 al-Dimashqī describes the marvellous beauties of the Ḥamā lands watered by the water-wheels:

“... le royaume de H’emât...là est la résidence du roi sultan, gouverneur indépendant ; c’est une belle ville et très fertile, riche en produits et en ressources pour les habitants.

Elle est entourée par le fleuve ʿAṣî, dont le cours inférieur la divise en deux parties,

\textsuperscript{229} See Chapter Four for a discussion of the links between mills and hydraulic norias on the Orontes.

\textsuperscript{230} It is also possible that he had been influenced by the studies in the chapter on water-wheels of the anonymous treatise written between the 9th and the 12th century, which was copied in the 12th century military manuscript \textit{Al-hiyāl fil-hurūb wa fath al-madāʾin wa bīf ḫ al-durūb}, as mentioned in the previous chapter. The similarity between the shape and the structure of the wheels described in this manuscript and those on the Orontes is impressive (Figs. 62 and 132). There is also an evident correspondence in terms of geometric construction, proportions and function of the wheels.

\textsuperscript{231} Abu’l-Fidāʾ 1848, 61. The \textit{Géographie d’Aboulféda} is the French translation done by Reinaud from the Arab manuscripts of Paris and Leiden.
combined par un pont ; sur ce fleuve, il y a une quantité de machines hydrauliques d’une construction qu’on ne voit nulle part ailleurs, servant à entretenir des courants d’eau considérables pour l’arrosement de jardins nombreux et riches en fruits excellents et beaux, tels que l’abricotier à goût de camphre et d’amande, qu’on ne trouve dans aucun autre pays…”

Ibn Baṭṭūṭa, in the early 14th century, was also impressed by the wheels near Ḥamā where:

“there are hydraulic wheels which look like celestial globes which turn”

He also mentions that a poet and traveller from Granada, known as Abu’-al-Iḥsān ‘Ali, composed verses about Ḥamā comparing the sound of the wheels to moaning and crying:

“Elles gémissent et versent leurs larmes; et l’on dirait qu’elles se passionnent en voyant ces pleurs et implorent leur affection.”

As the sources already quoted have demonstrated, the earliest hydraulic norias in Syria were constructed at least as early as the 3rd century A.D., following the technical and detailed descriptions done by Vitruvius in the 1st century B.C., whose treatise is the earliest work referring with certainty to hydraulic norias.

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232 Al-Dimasqī 1874, 281.
233 Ibn Baṭṭūṭa 1853, 141.
234 Ibn Baṭṭūṭa 1853, 142-143. The work which Ibn Baṭṭūṭa refers to could be the Tuhfat al-Albāb, which the 12th Hispanic-Arab traveller and geographer Abū Ḥamīd al-Gharnāṭī wrote between 1162 and 1165, where he described his travels around Europe and the Middle East.
235 The probable existence of hydraulic norias in the Ḥarrān area in the 7th century B.C. is based on interpretations of cuneiform scripts which do not prove with certainty that these installations already existed in Syria in that period.
The original design of the wheel was probably different to those in existence today. The mosaic found at Apamea refers to an installation which existed in the 5th century. It had the triangle like the installation today, but the design of the wheel is not the same. The wheel has radial spokes which start from the centre. This precise radiality is a characteristic of Roman water-wheels, as shown in the remains of the 2nd century A.D. hydraulic norias found at Venafro, in Italy, and at Barbegal, in France and also in the 1st century B.C. drawings of Vitruvius. The water-wheel represented in the *Hortus Deliciarum*, which refers to a scene dating to the 1st century A.D, also shows the Roman “radial” shape.\(^{236}\)

With the advent of Islamic technology the design of the wheel may have changed, although we do not know exactly when. The drawing of a wheel, which turns because of the weight of the mercury filling the pipe-spokes, in the anonymous Arab military manuscript written between the 9th and the 12th centuries,\(^{237}\) is very similar to modern designs used for building the hydraulic norias on the Orontes. The drawing shows a wheel with 24 spokes (Fig. 62) like the examples on the Orontes (Fig. 132). The geometric construction is the same. In both cases the intersection of two star-shaped dodecagons determines the position of the spokes of the wheels. The only difference lies in the position of the main spokes. In the manuscript they are radial, while in the Orontes wheels they are perpendicular to each other and are the load-bearing part of the wheel.

At present we do not have evidence of the shape of this wheel in the first two centuries of the Islamic period. Thus, we can suppose that the original Roman

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\(^{236}\) For the details of these sources see Chapter Two.

\(^{237}\) Hassan & Hill 1986, 70. This is the original treatise whose chapter on water-wheels may have been copied in the *Al-hiyal fi’l-hurūb wa fath al-madā’in wa hīfiz al-durūb* mentioned in Chapter Two.
shape may not have changed before the 9th century A.D., when the anonymous manuscript was written. Therefore, it is likely that the studies in the military manuscript may have had a bearing on the first design of the Orontes wheels. This design guarantees optimum use of the great power of the Orontes. As the wheel shape corresponds closely to the wheels in use today, it is likely that the original Islamic design has not changed.

1. THE SĀQIYAS AND NORIAS

While the sources and remains relating to the existence of hydraulic norias are numerous and allow us to date the Syrian hydraulic norias back to at least the 3rd century A.D., a few sources documenting the earliest existence of water-wheels moved by animals have been found. The lack of remains of sāqiya and norias can be explained by the fact that they were mainly housed underground, and consequently it was difficult to find them. In addition they were mostly composed of wooden parts (wheels), i.e. of a perishable material.

According to Nortedge, sāqiya pots from Dibsi Faraj, on the Euphrates, dating from the 4th century A.D., are the earliest evidence of the existence in Syria of the animal-driven sāqiya. However, it is likely that this typology entered Syria earlier, during the period of the Roman empire, probably the 3rd century A.D. In fact the Muḥyī l-Dīn Shaykh sāqiya, although it traditionally dates back to the 13th century, shows an impressive similarity with the late Roman device found at

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238 As already noted, according to Hassan and Hill (Hassan & Hill 1986, 70), the original military manuscript must have been written between the 9th and the 12th centuries.
240 Yūsuf 1990, 186-187. A discussion of this machine is in Chapter Five.
Fonnia, in Italy (Fig. 105). Both machines belong to the type of sāqiya with an elevated shaft, of which only a few examples have been found, and show the same horizontal cog-wheel. Also in the top of the tower the connection between the laqqāta and the tabqq is the same in both machines (Figs. 106-108). It is possible that the architect who built the Muḥyī l-Dīn Shaykh sāqiya may have seen similar machines in the area, which have now disappeared, but which may date back to the Roman period.

However, there is the possibility that the sāqiya and noria were introduced in Syria earlier, when the typology of the fujjāra (pl. fujjarāt) entered Syria in the 6th century B.C. Fujjarāt are underground channels which carried water from a natural source to an underground basin. From there water was raised by a sāqiya or noria. Some vertical shafts are dug into the hill and connect the channel to the surface. They were employed both as air shafts and for access to the underground level.

The fujjāra is slightly different from the qanāt (pl. qanawāt), i.e. a subterranean tunnel that taps the groundwater and leads the water to human settlements and agricultural lands by gravity.241 Underground water, coming from natural sources or from rain, flows into the channel which has a slight slope, and arrives outside. The tunnel extracts groundwater from a depth of 15 metres and carries it underground until it reaches the surface in the middle of the village.242

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241 Although Weulersse (Weulersse 1946, 283-284) specifies the function of the Syrian fujjarāt to carry water to an underground well, from which water was raised by an animal-powered machine, fujjarāt or qanawāt are used to indicate the same constructions, in spite of the differences which characterise them (Safadi 1990, 287).

Qanawāt can reach a length of more than 10 kilometres, and are particularly common in the Syrian steppe.\textsuperscript{243}

The qanāt was most probably introduced into Syria by the Persians, when Syria was incorporated as a province within their empire in the 6\textsuperscript{th} century B.C.\textsuperscript{244} Because of the similarity with the qanāt, it is possible that also the fujjāra appeared in the same period. In this case, the origin of sāqiyas and norias may date to the 6\textsuperscript{th} century B.C.

\textsuperscript{243} In particular, there are still significant examples at Palmyra and in the Ḫoms and Aleppo areas (Soumi and Abdel Aal 2001, 85).

\textsuperscript{244} Lightfoot 1996, 3.
CHAPTER FOUR

SYRIAN HYDRAULIC NORIAS

1. INTRODUCTION

The types of Syrian water-wheels are hydraulic norias, norias and sāqiyas. Most installations have been found in western Syria (Fig. 109), while on the East side only a few remains of masonry works of hydraulic norias have been found on the Euphrates and on the Khabūr river, a Euphrates tributary.245

In western Syria there are mainly hydraulic norias, which are analysed in this chapter. Sāqiya and noria will be dealt with in the following chapter.

Hydraulic norias grouped along the Orontes river are all compartmented hydraulic norias, but it is likely that until the 19th century most of them had pots instead of compartments. In fact al-Muḥammadiyya, which is one of the most significant installations built at Ḥamā, is a hydraulic compartmented noria and is the same machine described by Burckhardt in 1822 as “a means to supply water by buckets”. Burckhardt, talking about the system for raising water at Ḥamā, said:

“...There are four bridges over the Orontes in the town. The river supplies the upper town with water by means of buckets fixed to high wheels (Naoura), which empty themselves into stone canals, supported by lofty arches on a level with the upper parts of the town.

245 As far as the few remains of hydraulic norias in East Syria are concerned, these aspects will be dealt with only marginally in this thesis in order to counterbalance the prevalent emphasis on the great number of hydraulic compartmented norias surviving on the Orontes river. A discussion of the hydraulic norias on the Euphrates and Khabūr can be found in the paragraphs “Hydraulic norias in East Syria” later in this chapter (pp. 139-141).
There are about a dozen of the wheels; the largest of them, called *Naoura el Mohammedye*, is at least seventy feet in diameter..."\(^{246}\)

In addition Ewbank noted:

"...The city (Ḥamā) is built on both sides of the river, and is supplied with water from it by means of them (water-wheels), the buckets of which empty themselves into stone aqueducts..."\(^{247}\)

It is possible that the wheel of the *al-Muḥammadiyya* installation was first a wheel with pots, and was then converted into a wheel with compartments, probably in the second half of the 19th century, i.e. during the period between Ewbank’s assertion and the oldest photographs reproducing the Ḥamā installations, which date from the early 20th century (Fig. 301).\(^{248}\) However, this hypothesis is not very likely because of the large size of the wheel, which has a diameter of more than 20 metres. In fact hydraulic norias with pots were characterized by a wheel with a small diameter, like those on the Euphrates and Khabūr.\(^{249}\)

The Arabic name of the Orontes is *al-ʿAsī* and means “the Rebel” due to the fact that it flows in a contrary direction to most other rivers, that is, from the south to the north.\(^{250}\) The springs which feed the Orontes are in the mountains of Lebanon and anti-Lebanon and guarantee a great quantity of water to this river.

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\(^{246}\) Burckhardt 1822, 146.

\(^{247}\) Ewbank 1842, 115.

\(^{248}\) The mosaic from Apamea (Fig. 44), which is the earliest iconographical source for the hydraulic norias on the Orontes, also does not clarify whether the means to raise water was originally buckets or compartments.

\(^{249}\) Girard et al. 1990, 380.

\(^{250}\) This river was called by the Greeks *Ajax cos xoios*, from the old Syrian name of “Atzoio”, meaning “The Rapid”. The Arabs corrupted this name into *al-ʿAsī*, calling it also *al-Moklūb*, “The Overturned” (Le Strange 1890, 59).
From Lebanon, north of Baalbek, it flows towards the north, enters Syria, crosses Ḥoms, Ḥamā, arrives at the lake of Apamea and flows into the Mediterranean near Antakia in the Turkish district of Iskenderum (Fig. 110). The Orontes flows for about 600 kilometres, of which about 300 are in Syria. As it flows through Syria, its volume is increased by several tributaries. In many sections of the river, the banks are considerably higher than the level of the water. For this reason, the employment of a machine able to raise water from the river for irrigation has been necessary.

In Syria the Orontes valley has been the ideal place for the development of numerous hydraulic norias. In fact the construction and use of the hydraulic norias is allowed by favourable conditions, that is, the constant speed of the river, the gradual slope of the ground and the absence of consistent floods. In particular the constant speed of the water enables the hydraulic norias to move continuously. The necessary quantity of water is allowed by the Qaṭṭīna lake south of Ḥoms, which acts as a reservoir, while man-made barrages regulate the flow of water into the Orontes. Consequently, there is no risk of an excessive scarcity of water. In the case of small floods, these cannot be dangerous because the embankments always exceed the river level in height.

1.1. THE DIFFUSION

In western Syria there were around one hundred of these structures. Most of them were grouped along the Orontes from Ḥoms to the Turkish border.251 They were

251 Weulersse 1946, 257-258.
concentrated between Rastan and al-'Ashārīna (Figs. 110-111 and enclosed map) in a section about 100 kilometres long. Of these installations, seventy groups still exist. Twenty wheels still work in fourteen different sites.

At Rastan, north of Ḥoms, there was a hydraulic compartmented noria (Fig. 112) which was destroyed between 1939 and 1940 due to an increase in the river level. It was rebuilt some years later and definitively destroyed in the 1960s, when a new dam was built.

The scarcity of installations in the Ḥoms area is due to the fact that the lands are flat and the level of the river is almost the same as the level of the surrounding fields. There were three hydraulic norias: two employed for irrigation and located outside Ḥoms, and one built in the city and employed to supply water to the nearby mosques.

Of the two installations outside Ḥoms, one existed at al-Minias until the 1960s when it was replaced by a mill for grinding. The other is located between Ghajar Amīr and Kafar Nāna, north of Ḥoms. It is evidently an installation built recently because of the technique and materials employed, i.e.

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252 This is the section where there are ideal conditions of the river, as mentioned above, to enable the construction of hydraulic norias.
253 A survey of all surviving installations along the Orontes river is contained in Chapter Seven.
255 The existence of these two norias is noted by Baroja (Baroja 1954, 70) and Weulersse (Weulersse 1946, 257).
256 Between the Qatîfīna lake and Ḥoms six mills for grinding have been found during the survey done in 2005. The only mill still in operation is that at Umm Ghari̇f. It includes three wheels made of steel and wood which, moved by the force of the river, turn big millstones (Figs. 113,113a and 113b). The mills along the Orontes, i.e. those in the Ḥoms area and those associated to hydraulic norias in the Ḥamā area, are characterised by the same typology. They are parallelepiped stone constructions with two vaulted floors. On the ground floor, which corresponds to the upper level, there are the stone mills for grinding crops. The lower level houses the wheels which are partially submerged in the water and inserted in an aperture-channel in order to be moved by the current of the river. Every wheel transmits the rotation to a millstone by a vertical axle connecting the two devices. The apertures consist of a row of small square-shaped windows on the upper floor, and the aperture-channel on the lower floor (Figs. 113-113e).
basalt and reinforced concrete.\textsuperscript{257} This hydraulic noria may date from between the 1940s and the 1950s, i.e. before the construction of the dam at Rastan and the beginning of the use of modern pumps (in the 1960s), but after the introduction of reinforced concrete constructions (around the 1930s). The wheel does not exist any longer, while the masonry works of reinforced concrete (pillars and aqueduct channel) and basalt (tower, triangle and pillar cladding) are in a good state of preservation. The tower and triangle are in perfect condition, as are some pillars and part of the aqueduct channel (Figs. 114 and 115). It shows the typical feature which characterizes the 20\textsuperscript{th}-century hydraulic norias built on the Orontes, which have a reinforced concrete aqueduct channel supported by a row of square pillars clad in limestone or basalt, and a tower in basalt. The only difference lies in the shape of the tower window which is rectangular, instead of arched. This installation was built close to a previous mill for grinding crops, in an area characterized by a strong river current.\textsuperscript{258}

The installation in the city of Homs was probably originally constructed in the 12\textsuperscript{th} century and was of the same type as those in the Hamāa area. It was a single hydraulic compartmented noria with a wheel made of wood and 24 spokes.\textsuperscript{259} This installation existed until the first quarter of the 20\textsuperscript{th} century. In 1922 it was replaced by an installation with a wheel made of steel (Figs. 116 and 117). In the 1960s it was destroyed when a channel which derived from the Orontes, was closed. It was in the central area of the sūq called “sūq al-nā‘ūra”. It

\textsuperscript{257} This technique is also used for the new constructions and restorations of many hydraulic norias in the Hamāa area (see the survey enclosed), as, for instance, in Qabibāt al-‘Āṣī and al-‘Asīla (Figs. 159 and 164).
\textsuperscript{258} Of the ancient mill only a few remains have survived.
\textsuperscript{259} al-Zahrāwī 1992, 73.
was not used for irrigation, but to supply water to the two mosques nearby.\textsuperscript{260} Water was raised from the river in the wheel compartments and entered a vertical channel near the wheel. Through an underground channel water arrived at the two mosques.

Along the Orontes, near the Turkish border, there were three installations at Jisr al-Shughur and four installations at Darkūsh.\textsuperscript{261} All these have now completely disappeared.

A small number of hydraulic compartmented norias (Figs. 118 and 119) also existed in the Aleppo area on the Quwayq river until the 1950s. The hydraulic norias in Aleppo vanished after the course of the Quwayq river had been diverted.\textsuperscript{262} The masonry structure was of the same type as the Orontes installations,\textsuperscript{263} while the shape of the wheel was different, as shown by the hydraulic noria which was located in front of the National Museum (Khaṭṭāb Museum) (Fig. 118),\textsuperscript{264} and which existed until 1902. It was characterised by a radial disposition of the spokes and numerous paddles placed between the two external rims. Similar wheels have been found in Spain at Murcia (Fig. 31) and in France at Isle-sur-Sorgue (Fig. 120).\textsuperscript{265} According to Mubaiyyīd, the example at Aleppo (Fig. 118) may date from 60 B.C.\textsuperscript{266} The lack of convincing evidence for

\begin{itemize}
\item \textsuperscript{260} al-Zahrāwī 1992, 74-76.
\item \textsuperscript{261} Baroja 1954, 70; Weulersse 1946, 257.
\item \textsuperscript{262} Roumi 1985, 59. A. Russel (Russel 1794, 48), talking about the city of Aleppo, already wrote that “the inhabitants of Aleppo raised water from the river with the Persian wheel”, referring to the hydraulic noria with pots, according to the common definition used for this typology until the 19th century (Ewbank 1842, 115).
\item \textsuperscript{263} The lack of comparable architectural material does not allow us to understand if there were different tower and aqueduct designs as for the Orontes installations.
\item \textsuperscript{264} Girard et al. 1990, 380.
\item \textsuperscript{265} Townsend had already noted an amazing relationship between the Spanish wheels and the ruins of a construction in Aleppo. This construction, although Townsend did not specify the typology, could just be the hydraulic noria located in front of the National Museum.
\item \textsuperscript{266} Mubaiyyīd 2004, 13.
\end{itemize}
this is counterbalanced by the fact that it shows the typical Roman radial shape, as visual sources, dating from Roman times, have shown.\textsuperscript{267} This shape may have been transmitted until the above-mentioned example in Aleppo, while on the Orontes it may have changed with the advent of Islam.\textsuperscript{268} The new Orontes shape could have been developed especially for the unique conditions of the river; the wheel needed to guarantee the best distribution of the internal forces involved\textsuperscript{269} in order to support the strong water pressure on the wheel paddles, while, owing to a weaker current, the Aleppo water-wheels would have preserved the original shape.\textsuperscript{270}

The Orontes hydraulic norias are no longer used for irrigation. Some installations are kept in working order for reasons of historical architectural heritage.\textsuperscript{271} Nowadays the irrigation of the Orontes area is guaranteed by modern hydraulic pumps which raise water from the river or artificial basins and pour water into a network of artificial channels directed towards the fields.\textsuperscript{272}

The quantity of water raised depends on the size of the wheels, which ranges between seven and more than twenty metres.\textsuperscript{273} When they were in use, the average water raised was about 45 litres per second, which allowed an irrigation of 25 hectares. However, for the biggest installations, sometimes this average could reach 150 to 180 litres per second and could irrigate up to 50 to 75

\textsuperscript{267} See also pp. 69-71 in the paragraph “Analysis of sources” in Chapter Two.
\textsuperscript{268} For a detailed discussion see pp. 95-96 in Chapter Three.
\textsuperscript{269} For the advantages provided by the structure of the Orontes wheels, see also pp. 136-137.
\textsuperscript{270} The Quwayq river, like other rivers on which water-wheels were built, does not have the same characteristics as the Orontes, whose water-wheels had to have a particular strong structure.
\textsuperscript{271} See also the paragraph “Management and maintenance” later in this chapter (pp. 107-109), and Chapter Six.
\textsuperscript{272} For a discussion of the modern irrigation systems of the Orontes area see Chapter Six.
\textsuperscript{273} The biggest hydraulic noria on the Orontes is al-Muḥammadiyya, which has a diameter of 21.5 metres.
Hydraulic norias were mainly employed for irrigation, and also to supply water to the city of Ḥamā, that is to mosques, hammams, khans, houses, public fountains and gardens. They were usually named after the fields which they irrigated, the name of the founder-donor or the name of the nearest village, or, as in the case of al-Rawaniyya, the name of the designer.\(^\text{275}\)

1.2. ARCHITECTURE AND LANDSCAPE

The type of the hydraulic norias on the Orontes is that of the compartmented type, described in Chapter Two. The masonry works include an aqueduct, a triangle and a tower,\(^\text{276}\) and, in most cases also secondary works (the dam, one or more supplementary channels, the main channel, the barrages) (Figs. 26, 27, 121 and 122).

The majority of these installations, except those located in the city of Ḥamā, are far from the state roads, and often it is necessary to cross large fields and woods to reach them. In fact they are completely inserted into the landscape, and this makes them even more fascinating.

These hydraulic norias show unique characteristics in terms of material. Their use of local wood and stone, together with the river water, allow a close integration of these installations into the landscape. In fact the ideal wood for building different elements of the wheels is available near the Orontes. Poplar

\(^{274}\) Weulersse 1940, 56.

\(^{275}\) Al-Rawaniyya, built in Ḥamā in 1990, is named after architect Rawdan Lazkani who designed the installation.

The classification of the names is not universal. Names already published often do not correspond at all. This is due to the fact that in some cases an installation including more than one wheel is known by one name. In other cases every wheel has its own name. Because of this it is difficult to specify a definitive number of installations on the Orontes.

\(^{276}\) Tower and aqueduct, although they are connected to each other, are analysed as two different parts of the installation, because of their different architectural characteristics.
plantations can provide timber up to 15 metres long to make the spokes for the
large wheels, and wood which is easy to work to make the small parts. Mulberry
is the ideal material for the load-bearing axle of the wheel. The limestone
employed for the masonry works may not at first seem ideal because of its
permeability. However, because the water of the Orontes is rich in calcium, it
tends to deposit a thin layer on the limestone walls, thereby making them water­
proof. In addition, the lightness of the structure of the wheels often makes them
appear part of the natural landscape.

On the Orontes two consecutive installations or groups of installations are
never very close to each other; they have to be distant enough to avoid the risk of
turbulence of the water, which could interfere with the smooth running of the
wheels.

1.3. MANAGEMENT AND MAINTENANCE

Most hydraulic norias were "common property", although some were privately
owned. The families which used the installation paid for its maintenance. The
installations were in use in Ḥamā until the 1950s when a municipal aqueduct was
built and the use of electricity became widespread. They were also employed
outside Ḥamā until the early 1960s\textsuperscript{277} when new irrigation systems were built
using new electrical pumps to raise water.\textsuperscript{278}

When the hydraulic norias stopped working many families did not pay
attention to the installations any longer and thus lost their property rights, so that

\textsuperscript{277} However some hydraulic norias were still employed for irrigation until the 1980s, like \textit{al-}
Bishriyyat, in Ḥamā.
\textsuperscript{278} For the new irrigation systems see Chapter Six.
the hydraulic norias became state property. Some still remained private property, like al-Kharīsa, al-Khūdura, al-Khaṭṭāb and al-Mardīsha.

Restorations started in 1960, but only for the wooden parts. They were done by independent artisans to the orders of the Governorate. A programme of complete restoration started in 1987, to keep the installations in working order as part of Syria's architectural heritage. This included not only the wooden wheels, but also the masonry works.²⁷⁹

The Government of Ḫamā deals with the restoration of the wheels themselves, while the associated masonry works are restored by the Department of Antiquities of Ḫamā.

To guarantee the maintenance of the wheels the Government of Ḫamā has established the Daʾīrat al-nawāʾīr (“Department of the norias”). This department has a yard where complete wheels and component parts are built (Figs. 135-143).²⁸⁰ Periodically employees of the department do inspections of installations which include wheels in order to evaluate which parts of the wheel need to be replaced or repaired and to maintain the site. The Daʾīrat al-nawāʾīr pays close attention in preserving the typical shape of the wheel, knowledge of which may

²⁷⁹ Because of a lack of maintenance for more than twenty years, masonry works are considerably damaged.
²⁸⁰ The Daʾīrat al-nawāʾīr was established in 1972 as an administrative office which employed independent artisans to work on the wheels. From 1985 the department employed and trained artisans directly, becoming a workshop and yard, and the restorations of the wheels were done by the employers/artisans of the Department.

For a short period, between 1992 and 1995, a “Higher Institute for the Industry” (a school where young people were taught to work in the fields of design and construction of the wheels) was also established. This institution was closed because apprenticeships were considered more productive than teaching in an external institute.
have been transmitted until now since medieval times.\textsuperscript{281} Restorations are done on site using replacement parts made in the yard.

The restoration of the masonry works include the construction or repairing of barrages and channels which regulate the level of water during periods of plenty and scarcity, allowing the wheels to work for most of the year. However, for almost five months a year, the level of the river is too low to be increased sufficiently for the wheels to work properly. In fact water kept by the dam, although it is directed to the main channel, is not strong enough to move the paddles of the wheel. Consequently the water accumulates behind the paddles which enter the river. When the water accumulated is enough to move the paddles, the wheel re-starts, doing a few turns, although the movement is erratic.

There is not a precise period during which the wheels work. It depends on the quantity of water of the river. If there is an excessive scarcity of water due, for example, to an excessive scarcity of rains, the wheels do not turn.

In the programme of restoration for 2005-2006, four new wheels will be constructed and installed (\textit{al-Kharīsa, al-'Ashārina, Kazo al-Kabīra and al-Nāṣiriyya}), and the masonry works of \textit{al-Jisriyya, al-Nāṣiriyya, al-'Ashārina and Shīzar} will be restored.\textsuperscript{282}

\textsuperscript{281} I am referring to the period, between the 9\textsuperscript{th} and the 12\textsuperscript{th} centuries, in which the Arab military manuscript, with a drawing of a wheel which has strong similarities with the Orontes wheels was written. For more information related to this issue, see Chapter Three (pp. 95-96).

\textsuperscript{282} See Chapter Seven, including the survey of the installations along the Orontes and the corresponding sequence of photographs (Figs. 114-115 and 147-390).

The programme of restoration by the Department of Antiquities (for the masonry works) and the Governorate of Ḥamā (for the wooden wheels) is expected to restore as many installations as possible, depending on the condition of the parts and what finance is available. In this plan of restoration in progress it is expected to restore the installations in better condition and which are easily visible and accessible (for example installations near main roads, as those at Shīzar, \textit{al-'Ashārina and al-Nāṣiriyya} and those in Ḥamā).
1.4. DATING

As has been pointed out in Chapter Three, the original design of the wheel would have changed with the advent of Islam. The new shape, which probably dates back to a period between the 9th and the 12th centuries, has been transmitted until now. Because wood cannot be used as a reliable source of evidence,283 the probable origin of hydraulic norias can only be determined by referring to the masonry works.

It is difficult to date the masonry works because of the continual alterations and repairs. They have often needed repairing and rebuilding as a consequence of numerous earthquakes which have happened over the centuries in the Orontes valley. The most violent earthquakes were those in 1157/552H and 1759/1173H, during which many installations were severely damaged.284

The dating of hydraulic norias is made yet more difficult through the widespread practice of using reinforced concrete for their repair or reconstruction, and covering them with limestone and basalt which are easily available in the Orontes basin and are similar to the original materials used. The recent restorations which are in progress are trying to preserve and display the original parts, to remove those of reinforced concrete added in the 1930s and 1940s, and, for those to be reconstructed, to adopt traditional architectural techniques which used local limestone, basalt and mortar.

A number of installations are recent constructions in reinforced concrete dating from the 1930s-1940s, but for other installations, a comparative analysis of

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283 This is because of the perishability of the wood.
the masonry structures with ancient architectural typologies and techniques, has been carried out to clarify the probable origin of the design.\textsuperscript{285}

In some cases inscriptions have been used as a source of evidence to discover the date of construction of hydraulic norias, although, in some cases, they refer to the date of the reconstruction of a hydraulic noria on the remains of a previous ancient installation, like in the example of \textit{al-‘Asharina}.\textsuperscript{286}

2. TYPES OF INSTALLATION

When it is necessary to supply a large amount of water, it is common to find hydraulic norias arranged in groups. A great part of hydraulic noria installations consists of masonry works. The parts made of wood, i.e. the wheels, due to their perishability, have always been replaced by new examples over the years. For the installations which do not preserve the wheel, understanding the type has been possible because the place for housing the wheel, and the number of wheels, are clearly recognizable by the number and the position of the triangles, towers and aqueducts.

Depending on the number and position of towers and aqueducts, three main groups of hydraulic norias have been determined (Fig. 123). Seven sub-groups

\footnotesize
\textsuperscript{285} Evidence shown by the historical sources has supported the attempt to understand the probable original design of some ancient hydraulic norias.

\textsuperscript{286} In some cases, \textit{waqfiyat} (legally attested deeds of endowment) and court logbooks, have helped to date some installations “ante quem” because they indicate a date when the hydraulic norias were already in use for irrigation. Thus, the majority already existed between the 14\textsuperscript{th} and the 16\textsuperscript{th} century. A small group already existed in the 18\textsuperscript{th} century (see also the survey in Chapter Seven).
have been identified, depending on the number and position of the wheels (Figs. 124 and 125).²⁸⁷

The first main group (Figs. 123 and 124; typology A) is the simplest and is composed of one aqueduct and one tower. This group includes two sub-groups. The first is characterized by one wheel (Fig. 125; typology A1). The majority of hydraulic norias belong to this type. At Ḥamā, al-Jisriyya (Figs. 240-248), al-Maʾmuriyya (Figs. 254-259) and al-Muḥammadiyya (Fig. 294-302) are the most representative for their perfect condition and their picturesque location in the city, while outside Ḥamā this typology is well represented by al-Jawhariyya (Figs. 307-311), zūr Abū Zayd (Fig. 370-373) and al-Ḥamdānī (Fig. 380-382). A further sub-group (Fig. 125; type A2) has two wheels with the same diameter, which supply the same aqueduct and are placed on both sides of the tower, like the smaller wheels al-Bishriyyat in southern Ḥamā (Fig. 233 and 234) and al-Ṣahyuniyya and al-Gharbiyya in the city of Ḥamā (Figs. 264 and 265).²⁸⁸

The second main group (Figs. 123 and 124; typology B) is composed of two hydraulic norias of different sizes to enable irrigation at different levels. This group of hydraulic norias includes three sub-groups. The first has two wheels, i.e. one wheel for each hydraulic noria (Fig. 125; typology B1). The second sub-group includes three wheels, i.e. one on one side of the smallest installation and two on both sides of the biggest one (Fig. 125; type B2). The

²⁸⁷ A survey of the installations is in Chapter Seven.
²⁸⁸ The Al-Ṣahyuniyya and al-Gharbiyya wheels have a slightly different diameter although they supply the same aqueduct.
third sub-group has four wheels, i.e. two wheels on both sides of each tower (Fig. 125; typology B3).

*Al-Bishriyyat* (Figs. 231 and 232) at Ḫamā, the group *al-Dawwār* and *al-Sahiriyya* (Fig. 213 and 214) and *al-Jūmaqiyya* (Fig. 165 and 166) in southern Ḫamā are the best-preserved examples of this type of installation.

The third main group (Figs. 123 and 124; typology C) is composed of two identical parallel towers connected to each other by one aqueduct. In this case the wheels always have the same diameter.

The first sub-group (Fig. 125; typology C1) includes two wheels placed on one side of each tower; the second one (Fig. 125; typology C2) has four wheels placed on both sides of each tower. This typology is to be found in four installations: *Marij al-dur*, which included four wheels (Figs. 157 and 158), ‘Abla and ‘Antar, which had two wheels (Fig. 229), *al-Khattāb* (two wheels) (Figs. 351-354) and *al-Murtaqab* (two wheels) (Figs. 342-346).

3. MASONRY WORKS

As has been pointed out, masonry works are composed of an aqueduct, a tower, a *triangle* and a dam (Figs. 26 and 27). Most masonry works are made of local limestone or basalt and mortar. Aqueduct and tower are perpendicular to each other, creating an “L”-shaped layout (Figs. 26, 27 and 123). They have the same height, which is between 6 and 18 metres, while the length of the aqueduct can

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In some 20th-century constructions, the aqueducts are built in reinforced concrete covered by basalt, the towers and triangles are made of basalt or reinforced concrete and the dam is usually made of concrete (Figs. 114, 115, 159, 160, 365-369).
They are slightly lower than the wheel to allow the pouring of water into the aqueduct channel.

The tower is characterized by a central arched window for supporting the axle of the wheel and by two stepped corbels (Fig. 129) on the upper corners, in order to reach the exact points of contact between the external rim and the tower (Fig. 130). These corbels, which have an aesthetic function, can also consist of an overhang of the wall (Fig. 227). In both cases the corbels give more elegance to the design of the elevation.

The central window of the tower is one of the places used for the maintenance, repair and assembly of the wheel. For large installations, there is another place for maintenance which consists of a niche at the bottom of the tower (Figs. 175, 210, 316, 319).

The diameter of the wheel depends on the size of the original tower which is circumscribed by the circumference of the wheel. The small-sized wheels are connected to towers whose shape develops horizontally. By contrast, large-sized wheels are connected to slender towers, like al-Muhammadiyya, with a wheel exceeding 20 metres in diameter and a tower with a height double the length of the base (Fig. 122). This characteristic allows small and large wheels to raise and transport nearly the same quantity of water in the same time. In fact the submerged part of the small wheels is bigger than the submerged part in large wheels (Fig. 130). Another reason why the water raised is almost the same in big

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290 This is the case, for instance, with the al-Qarnāsiyya aqueduct.
291 Towers, as well as aqueducts, are characterised by drop arches. The ratio between span and radius is 7:4. As Delpech has noted, this type of arch is typical of the Ḥamā area (Delpech et al. 1997, 34-35).
292 As will be noted in the following paragraph - "Variations in masonry works design" - many towers have been modified over time, transforming their shape from rectangular to square (Fig. 128a).
and small structures is that the big wheels turn slower than the small wheels, owing to the inertial force, and consequently lose more water during the transfer to the tank than the small wheels.

Installations or groups of installations can be placed at one end of the dam or at both ends of the same dam. In the first case the dam is placed diagonally across the river, in order to direct the current towards the main channel which houses the wheel. When the dam connects two installations placed at both its ends, it is orientated perpendicular to the river flow in order to guarantee the best level and speed of the water. Most hydraulic norias share the same dam, to fully exploit their function and reduce the number of dams crossing the river (Fig. 127). These positions of hydraulic norias are numerous along the river banks outside the city, in areas close to large fields in order to irrigate them.293 Along the length of the dam there are passages of water to regulate the river level during periods of flooding or low water. They are barrel-vaulted in shape. Water passes through the passages when the river is in flood (Figs. 185, 194a). When the river is low, however, they are barred in order to direct the water to the wheel.294

It is also possible to find one or more supplementary channels which are built beside the main channel. They are parallel to the main channel and contribute, when necessary, to evacuate the excessive quantity of water (Fig. 171).

293 To understand the great quantity of hydraulic norias placed at both ends of the same dam, see the survey in Chapter Seven which includes a complete list and classification of the installations.

294 To allow all the water to flow towards the main channel, when the river is deep and narrow, it was possible to find, rather than a stone dam, a barrage made of two courses of timber frames connected to each other (Zaqzouq 1990, 360). Because of the perishability of the wood, this kind of barrage no longer exists.
To increase the water flow towards the main channel, barrages cross the supplementary channels allowing the flow to be regulated.

To guarantee a consistent quantity of water to move the wheel constantly, the channel which houses the wheel has a small width (Fig. 172). The channel is very narrow (only 1 metre wide) and is entirely occupied by the wheel. Only 10-15 centimetres separate the wheel from the walls of the aqueduct and tower and from the base of the channel (Fig. 216). In this way it is possible to exploit the power of water as much as possible. When it is necessary to stop the rotation (for example, for maintenance), the channel can be closed by a lock to prevent water from passing through.

The triangle, which, through the steps on its sides, allows access to the nave of the wheel for maintenance, can also have some wooden struts, on one of its triangular sides, which function as steps to reach the sill of the window (Fig. 220).

Associated with an old installation it is also common to find a mill with its own wheel for grinding which employed the power of the river provided by the masonry works of the hydraulic noria. In this case the mill can be located beside the installation, or on the opposite bank (Figs. 150, 188, 192, 194, 291, 304, 313). In the latter case mill and hydraulic noria are connected by a dam. In some cases, a wheel for raising water was located on the external wall of a mill for grinding, like the *al-Awaniyya* of which only the mill remains (Figs. 305-306).

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295 Maintaining the right speed of the water is very important. An excessive speed can break the wheel, as happened in 2003 with *al-Bishriyyat* at Ḥamā, when it was necessary to entirely replace the twin wheels.

296 Despite their rustic aspect, the mills were particularly important for the economy of the area. The villages on the Orontes were above all manufacturers of cereals (Weulersse 1940 (a), 59). For the characteristics of the mills on the Orontes see note 256.
Because hydraulic norias (although not in use for irrigation, but preserved as historical monuments) are kept in working order, a great quantity of water and the right river flow are guaranteed by the masonry works. Consequently it is often possible to find modern hydraulic pumps for irrigation placed close to the old installations in order to exploit the quantity of water provided. It is also possible to find modern aqueducts built near the remains of an old structure, in order to benefit from the advantages provided by the masonry works (or their remains), like in the case of zur al-Traymisa. In some cases, like in the Kharīsa and zur Abū Zayd installations, the aqueduct channels are still employed for carrying water raised by the pumps to the fields (Fig. 207 and 370).

3.1. VARIATIONS IN MASONRY WORKS DESIGN

In spite of the simplicity of the masonry structure, towers and aqueducts show various designs and architectural characteristics.

Tower

Five different types of tower have been determined (Fig. 128a).

The simplest and most common type of tower is rectangular with an arched window (Fig. 128a; typology A). Because the diagonal of the tower always

\[297\text{ Although today electrical pumps located near the installations are employed to raise water from the river for irrigation, they are not able to raise the same quantity as hydraulic norias. Consequently the surrounding lands are not as green and luxuriant as in the past when hydraulic norias, "had transformed the valley to a continuous ribbon of greenery and shade which cut through the arid land" (Weulersse 1946, 258).}\]

\[298\text{ Unfortunately in some cases, like that of al-Wajiyāt where the end of the aqueducts had collapsed, new houses were built on the foundations of the collapsed aqueduct, consequently obstructing its original course. In this way the aqueduct channel enters directly into the houses, providing water, raised by electrical pumps, for domestic purposes and precluding the possibility of a subsequent restoration of the structure (Fig. 450).}\]
has the same length as the diameter of the wheel, in installations where the wheel is not preserved, it is possible to reconstruct the dimension of the wheel easily (Fig. 130).

From this type of tower, which is probably the most ancient of those identified,\textsuperscript{299} seem to derive the other four types of tower. Thus, by adding a rectangular wall, characterized by one or two arches, on one side of the original tower, the new tower becomes square in shape (Fig. 128a; typologies B, C, D and E). It is possible that the change of shape of the tower was made during restorations, as in the \textit{al-Ma'mūriyya} example in Ḥamā. The original part of the aqueduct, marked by an inscription with the date of construction (1453),\textsuperscript{300} changes orientation before it connects with the tower (Figs. 255-256). To connect aqueduct and tower, the original tower had to be enlarged.\textsuperscript{301}

The types of square tower show variations which depend on the shape and position of the apertures.

There is the type where the added wall has a simple portal (Fig. 128a; typology B). This design can be seen, for instance, in \textit{al-Taqṣīs} (Fig. 174). It has been re-employed in the construction of some 20\textsuperscript{th}-century installations, as in the hydraulic noria at ‘Ashārina (Fig. 390). This shape of tower also characterizes

\textsuperscript{299} The \textit{Al-Kharbānā} tower (Figs. 338-339) is probably one of the oldest on the Orontes and no restorations seem to have been done, like the remains of \textit{al-Jūnūqiyya}, \textit{Qūbībāt al-‘Aṣī}, \textit{zūr al-Sūs}, \textit{zūr Trämisu}, \textit{al-Mahrnqta} and \textit{zūr al-Thalāthā}. This is probably due to its isolated location which is extremely difficult to reach. The small square aperture on the upper corner indicates the connection with the aqueduct, which has completely disappeared.

\textsuperscript{300} See also the already mentioned survey.

\textsuperscript{301} The two windows in the upper part of the original tower may have been additions done during restorations.
installations which have two identical towers connected to the same aqueduct, like Marīj al-dur and the group ‘Abla and ‘Antar.

A variation of the tower discussed above has the added wall with two superimposed arched windows (Fig. 128a; typology C). An example of this version is the al-Khattāb tower (Fig. 352).

A further group of square towers, especially the large ones at Ḥamā, has the first part, connected with the wheel, with more apertures (Fig. 128a; typology D). There is normally a window in the centre of the rectangular tower to support the wheel and two windows placed symmetrically in the upper part of the tower. The second part of the tower, i.e. the added wall, is characterized by a high arch at the first level superimposed by an arched window. Al-Ma’muriyya, in Ḥamā, has this feature (Figs. 257 and 258).³⁰²

The last sub-group is similar to the previous one. The only difference consists of the presence of one arched window at the first level of the added wall instead of two superimposed apertures (Fig. 128a; typology E). We can see this type in al-Bishriyya al-Kubrā at Ḥamā (Fig. 238).

**Aqueduct**

Five types of aqueduct have been determined (Fig. 128b).

The simplest version is an ordinary aqueduct consisting of a long row of arches (Fig. 128b; typology A). Depending on the size of the aqueduct and on the slope of the ground, the row of arcades can have arches supported by high piers, or built directly on the ground. In the first case the installations are usually built in

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³⁰²See also note 301. A reason for the presence of more apertures at the upper level may be the necessity to have more places for maintenance.
quite flat areas, as in the city of Ḥamā, while the second case is ideal for aqueducts built on steeply sloping ground.

A variation of this type of aqueduct is represented by the monumental *al-Jumāqiyya* hydraulic noria (Fig. 165), which is an example of a double installation where the two aqueducts at different levels, with semicircular arches made of local basalt, follow the slope of the surrounding hills.

A different aqueduct design is characterized by a double row of arcades (Fig. 128b; typology B). This type is usually adopted for large hydraulic norias for structural reasons, and also in order to lighten the structure for aesthetic reasons, like in *al-Bishriyyat* (Fig. 230). The arcades of *al-Bishriyya al-Sughrā* (the smaller) and those of the lower level of *al-Bishriyya al-Kubrā* (the bigger) are in alignment and have the same size and shape. Thus, in elevation, the two aqueducts appear to be one (Fig. 232).

Another type of aqueduct (Fig. 128b; typology C) can be seen in *al-Mardīsha* (Figs. 332-335), which is particularly elaborate. Its design is based on a modular sequence of square motifs (Fig. 335a). Each arch in the lower level corresponds symmetrically to two arcades at the upper level.

The fifth type of aqueduct (Fig. 128b; typology D) consists of a multi-tier aqueduct made of stone which can be seen in *al-Qarnāšiyya* (Figs. 219-223). This shape, as will be shown, could originally have included a further row of arcades, in place of the upper collapsed wall.

Finally there are the aqueducts which belong to the most recent installations, built in the 1930s and 1940s (Fig. 128b; typology E). They consist

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303 In large aqueducts, superimposed tiers of arches are, in fact, one of the best solution adopted in order to guarantee stability to the structure (Trevor Hodge 2000, 73).
of a reinforced concrete sequence of pillars supporting an architrave-aqueduct channel. Often the pillars have a facing of local stone (basalt or limestone) as in al-‘Asila (Fig. 164) and al-Mishyâh (Figs. 167-169). Similar aqueducts were also built on the remains of ancient installations, such as, for instance, al-Shankiyya (Figs. 170-173).304

We can note that the differentiation of the five types of aqueduct identified depends on the characteristics of their immediate environment.

The first and last types, i.e. that consisting of a row of arcades, and the modern reinforced concrete one, are the ideal for most Orontes installations which are built on steeply sloping ground as well as on the flat (like those in the city of Ḥamā), without the need for significant alterations of their structural and architectural typology.

By contrast, the types characterised by two rows of arcades or more elaborate designs are usually built on flat or gently sloping ground, in order to allow a better distribution of the internal forces in the arches and to guarantee a uniform distribution of the loads on the foundations.

As will be shown, some installations have a construction technique similar to the Roman ones and similarities to Roman typologies. Although, as already discussed,305 we cannot say when these structures were built, it should be taken

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304 The recent programme of restoration of the masonry works aims to preserve the original stone structure and to rebuild the missing parts following the original shape. For instance in al-Jisriyya, in Ḥamā, it is expected that seven stone arcades will be reconstructed. Restorations done before the 1960s, however, did not use the same materials or shape as the original structures.

305 See the paragraph “Dating” above, in this chapter (pp. 110-111).
into account that some installations may originally have been built in the Roman period and perhaps later reconstructed using shapes and techniques similar to those used by Roman builders. Some foundations could have survived due to the fact that the structures were built under the lee of hills and were, consequently, naturally protected from atmospheric agents, and because of the hardness and water-proof characteristic of the masonry works, owing to the calcium contained in the river water. Moreover, as historical records have shown, hydraulic norias have existed in the Orontes area since the 3rd century A.D., although there is no identifiable location for them on the river banks.

Ghūr al-‘Āṣī still preserves part of an ancient aqueduct channel which is covered with cut stone and mortar (Fig. 156) and shows a similarity with the typology of some Roman aqueduct channels, such as the Anio Novus aqueduct in Rome (1st century A.D.) (Fig. 398). The design of some aqueducts, such as those of al-Qarnāšīyya and al-Mardīsha (Figs. 219-223; 332-335), brings to mind that of some Roman aqueducts, while features of some towers, like al-Marta‘bani (Fig. 227) or al-Kharbāna (Fig. 338) show a slight resemblance to some triumphal arches with a single barrel-vault. The upper band of the tower, which corresponds to the aqueduct channel, evokes the characteristic attic storey of Roman arches,

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306 This hypothesis can only be provisional, as, at present, we do not have physical evidence of Roman remains.
307 Al-Mahruqa is probably built on a Roman foundation (Department of Antiquities of Hamā).
308 As already noted, calcium, which exists in considerable amounts in the water of the Orontes, tends to form a deposit on the walls of the masonry works, making them strong and impermeable.
309 For these installations, which will be described in detail, see the following paragraph “Originality in design. An analysis of case studies”.

122
and the niche for maintenance beside the window seems reminiscent of that in some Roman examples.\textsuperscript{310}

4. ORIGINALITY IN DESIGN. AN ANALYSIS OF SOME CASE STUDIES

Some installations have been analysed more in detail for their unique architectural aspects and originality of the design and, in some cases, for their probable ancient origin. They demonstrate that hydraulic norias on the Orontes were devised as architectural constructions whose design is not only intended to be functional, but also aesthetic. They also show an architecture which has been able to combine essentiality and simplicity, necessary for integration into the landscape, and an architectural shape whose geometric construction is based on schemes of symmetry, modularity and harmony.

The following examples, whose good state of preservation has enabled a better understanding of their shape, also represent differently elaborated designs which could have been representative of other installations of which only a few remains have survived. It has also been attempted, in some cases, to understand how their design could have been modified over time.

\textsuperscript{310} Some remains also show a structural technique similar to the Roman \textit{opus structile}, like \textit{zūr al-Thalāṭha} (Fig. 384), \textit{zūr al-Traymīsā} (Fig. 385), \textit{al-Murtqāb} (Fig. 346), \textit{al-Bunduqīyya} (Fig. 226) and \textit{al-Kharbānā} (Fig. 338-341). The \textit{opus structile} (or \textit{opus caementicium}) is a Roman structural technique which consists of a wall made of rough undressed stones placed in a concrete mix of lime, pozzolan, sand and water. It developed in the 3rd century B.C. in Italy and afterwards became widespread in the whole Roman Empire. It would have entered Syria in the 1st century B.C. after it became a Roman province under general Gnaeus Pompeus Magnus in 64 B.C. (Ward-Perkins 1981, 273-274). This technique can be seen, for instance, in the remains of Roman aqueducts on the upper Orontes, on the plateau of Daphne, from Daphne and Antioch (Wilber 1938, 52-53).
4.1. AL-QARNÄŠIYYA AND AL-JAHIDIYYA

This installation is composed of two hydraulic norias of different sizes, on the same bank. It is located on the southern outskirts of Ḥamā. It is in a silent and isolated place far from the nearest state road (Figs. 220-225). It is of the type composed of two hydraulic norias of different sizes to permit irrigation at different levels. Each installation had one wheel on one side of the tower (typology B1 in Fig. 125).\footnote{As already noted, on the side of the tower without a triangle namely Al-Qarnäšiyya (the biggest), the struts inserted into the wall were used as steps to reach the sill of the window.} The whole structure is made of shaped local limestone, local basalt and concrete.

Both triangles still exist, although the wheels have disappeared. There are still the towers, parts of the aqueducts and remains of the dam which is shared with al-Bunduqīyya, located on the opposite bank. The towers belong to the simplest type with a rectangular shape and a central arched window (typology A in Fig. 128a).

The uniqueness of this installation lies in the elaborate aqueduct design of al-Qarnäšiyya, i.e. the biggest hydraulic noria (Figs. 219-224).\footnote{The aqueduct of al-Jahidiyya (the smallest) consists of a row of arches (typology A in Fig. 128b).} It can be divided into two parts.

The first (Figs. 221-223) consists of a central high drop arch and two symmetrical rows of arches on both sides (typology D in Fig. 128b). The second part consists of a row of arches (Fig. 224) which are the continuation of the two upper arches of the first sector. The difference in shape may be due to the large size of the installation and the slope of the ground. The first sector is built on flat
ground. Where the ground acquires a slope, the aqueduct changes shape into a sequence of arches (second sector).

The first sector consists of a symmetrical division into three of the two-level façade. The upper part, which housed the aqueduct channel, has collapsed. Comparing the height of the tower with the wall façade, it is possible to note that the aqueduct would originally have been of considerable height, in order to reach the level of the aqueduct channel.

A probable reconstruction of the elevations suggests that four different shapes could have characterized the original façade (Fig. 223).

Considering that the piers are tall and thin\(^{313}\) to guarantee both longitudinal and lateral stability, one solution (type 1) could have been inserting a stone arch, or arches, about half-way up, cross-bracing each pier to its neighbours. This solution brings to mind some Roman aqueducts, like, for instance, that at Merida in Spain (1\(^{st}\) century A.D.).

The second reconstruction (type 2) shows the possibility of a system of repeated tall arches. This type is, however, less convincing. Because of the height of the piers, these would have been strengthened, but there is no evidence of the existence of buttresses.

An alternative could have been to build the aqueduct in superimposed tiers of arches (type 3). This feature derives from other Roman aqueducts like those at Terragona or at Segovia in Spain (Fig. 396). On the Orontes this type of aqueduct

\(^{313}\) These piers are not strengthened by buttresses as in the majority of aqueducts with a single row of tall arcades, like, for instance, al-Muhammadiyya.
is also to be found in the big aqueducts, e.g. *al-Bishriyya al-Kubra* or *al-Ma‘muriyya* in Ḥamā.

A further reconstruction (type 4) shows that the aqueduct could have had a façade similar to the existing one, but with a blank wall in place of the one that has collapsed its upper part. This type does not seem very likely. The excessive height of the upper part would have brought structural problems.

The type which seems most probable is type 1, because of the stability guaranteed to the structure and because it would not have involved many modifications compared to the actual remains of the façade.

The analysis of this installation shows what the original shape may have been, and how Roman architecture would have affected its design and its structural solutions.

Although we cannot say if this installation was built on the base of an original Roman model, we can assert that the type of aqueduct would also have been successfully adopted for those large-size installations on the Orontes, built on slightly sloping ground, for which the aqueducts are no longer in existence.
4.2. AL-MARDISHA

*Al-Mardîsha* installation is one of the most picturesque hydraulic norias in the Orontes valley. It is located north of Ḥamā in the area with the same name. It is quite far from the municipal streets and quite difficult to reach. Access is via a shady narrow path through the woods. The installation is private property and was in use until 1975 (Figs. 332-337).

It included one wheel which has now disappeared. There are still remains of the dam, the triangle (which seems to be a recent construction), the tower (which, in the upper part, has been rebuilt in reinforced concrete) and the initial part of the aqueduct (the continuation towards the fields, as well as the aqueduct channel, are recent constructions made of reinforced concrete). The oldest part of the aqueduct has two rows of arcades.

The aqueduct has a particularly interesting design based on a modular sequence of square motifs. Each arch at the lower level corresponds symmetrically to two arcades at the upper level. The lower intercolumniation of the lower arches is twice that of the upper arches. The height ratio of lower to upper arches is 3:2 (Fig. 335a).

As is possible to note, the central point of the sill of the aperture tower does not correspond to the centre of the tower itself. It is at a lower level than the centre of the fronton (Fig. 335). This means that originally the base of the tower was lower than now and the lower arcades were supported by pillars which are now partially submerged by the river. It is also probable that the aqueduct and

314 Despite the beauty of the place and the singularity of the design of the aqueduct, a new wheel and a re-use of the installation is not at present expected, because of its isolated location.
tower were built in two different stages because the aqueduct does not connect with the tower on the corner, but it is slightly moved towards the tower aperture, creating a layout with a “T” shape instead of the typical “L” (Fig. 335).

The probable original design, characterized by its rhythmic disposition of the two rows of arcades, brings to mind some Roman aqueducts, such as, for instance, the Saint Pollio aqueduct at Ephesos (Fig. 395), and also shows one of the commonest varieties of intercolumniations described by Vitruvius.315

4.3. AL-MUḤAMMADIYYA

Al-Muḥammadiyya installation is the biggest hydraulic noria on the Orontes. It is located at Bab al-Nahr, in the west part of Ḥamā. It is possible to reach the installation easily from the street by stone steps. (Figs 294-302). It is in good condition thanks to the constant restorations carried out by the local government.

It belongs to the simplest of the types determined (Type A in Figs. 128a and 128b). The aqueduct is more than 100 metres long and today it is partially interrupted by streets and houses. Its tower exceeds 17 metres in height and the wheel has a diameter of 21.5 metres, 24 spokes and 120 compartments.

The aqueduct consists of a sequence of arcades, of which 15 have been preserved, and, for the part of the aqueduct close to the tower, of two levels of arches. The arch at the lower level corresponds symmetrically to the two arches at the upper level.

315 At present there is no evidence of an ancient origin for this installation, about which we only know with certainty that it existed in 971/1560, when it was mentioned in the court logbook (Zaqzouq 1990, 153). It is possible, however, to take into account a possible preislamic origin here, in the light of its links with Roman norms and aqueducts together with the evidence, attested by the sources, of the existence of hydraulic norias on the Orontes since the 3rd century A.D., although the exact location of such hydraulic norias is not provided.
The existing construction dates back to 1362/763H, as indicated on the inscription on the pillar of the thirteenth arch. The inscription refers to the foundation of the installation: “This big and blessed water-wheel was constructed to carry water to the al-A‘lā Mosque in the days of our Lord, His Most Noble Excellency Saif al-dīn Ṭanyaraq, Viceroy of the province of Ḥamā, during the last days of the year 763” (October 1362). In addition to the Great Mosque, it provided water to the Hammam al-Dahab (which existed until the 1970s), to the gardens near the mosque and to the houses and fountains in the area.316

As already noted, the medieval construction of 1362 may have been built on the remains of a Roman installation which would have provided water to the 3rd-century Roman sanctuary, remains of which were found under the Great mosque.317 Probably the shape of the aqueduct was changed during the medieval reconstruction.

The shape of the aqueduct shows differences between the first and the second sections. It is possible that the original shape was similar to the design of the first section. This shape was frequently adopted in Roman aqueducts, and could have been the ideal solution to guarantee structural stability. In fact, the simplest system of repeated arches (which characterises the second section of the aqueduct) does not seem to be the best solution. Because of the considerable height of the piers, they are, in fact, strengthened with buttresses. The superimposed tiers of arches, which characterises the first section of the aqueduct, would have guaranteed a better stability to the whole structure. This shape would have created a rhythmic alternation of a double row of arcades, as at al-Mardisha.

316 Zaqzouq 1990, 345.
317 A discussion on this issue see pp. 89-90 in Chapter Three.
Thus, it is possible that this pattern was originally repeated along the length of the aqueduct and changed during the 14th-century reconstruction.

4.4. AL-TAQSĪS

Al-Taqṣīs installation is located in the zūr Taqṣīs area, south of Ḥamā, in an arid landscape with few trees or other vegetation (Figs. 174-176). The installation already existed in 981/1573, the date mentioned in the court logbook.\(^{318}\)

The peculiarity of this installation is the austerity, essentiality and simplicity of the design, and its close integration into the landscape. The design of this installation has also been frequently adopted in the 20th-century reconstructions of hydraulic norias on the Orontes like al-'Ashārina (Fig. 389).

It is composed of one aqueduct and one tower. Originally it had two wheels with the same diameter placed on both sides of the tower (typology A2; Fig. 125). Except for the two wheels, which have disappeared, and the dam, which is mainly in ruins, the whole structure is in good condition. The rectangular part of the façade (type B in Fig. 128a), i.e. the original tower,\(^{319}\) shows on the top corners the stepped corbels characteristic of the Orontes installations, and a window with a four-centred arch.

The perspective view of the row of arcades and their slender shape make the installation appear longer than it actually is. There is a detailed perfection in its shape and geometry. The use of two different arches also seems to be a precise architectural choice. The four-centred arch counterbalances the verticality of the

\(^{318}\) al-Kīlānī 1969, 96.

\(^{319}\) As it has been noted, this type of tower derives from the connection of the original rectangular tower, characterized by a central window, and a rectangular wall characterized by a high arch.
main tower, while the drop-arch underlines the perspective of the row of the aqueduct arcades.

This linear and essential nature of the arcades can also be found in simple versions of courtyard arcades of some Syrian caravansarais, for instance, that at Ma’arrat al-Nu’mān (Fig. 398c), a few kilometres from the Orontes valley.

4.5. Al-MASĀLIQ AND AL-ḤĀMĪD

A particularly interesting layout of hydraulic norias is the group al-Masāliq and al-Ḥāmid (Figs. 355-364a). The two installations, which are placed at both ends of the same dam, have the towers, triangles and wheels in the middle of the river, instead of on the banks. The parts of the aqueducts that lie on the river beds are perpendicular to the towers and to the river flow. When they reach the banks of the river, they change orientation to enter the fields (Fig. 364a). This layout was probably adopted as the river is shallow enough in the middle to allow the construction of towers and triangles.

The installations are also unique because of their asymmetrical layout which follows the nature of the landscape, becoming part of it (Fig. 355). Their asymmetrical position and the fact that they are very close to each other make them appear as only one installation crossing the river, gently inserting itself into the surrounding landscape.

This is one of the best examples of hydraulic norias integrated into nature. Unfortunately most of the original aqueduct channel and the upper part of some pillars have been lost and replaced by reinforced concrete.
5. THE WHEEL

Wood is employed to make all the parts of the wheel, including big dowels which hold the structure together (Fig. 140). All other elements are made of masonry.

Because the wood employed has to be hard, durable and flexible, the best type are hazel, mulberry and poplar, all of which are easily available in the Orontes area.\(^{320}\) The choice of wood depends on the types of stress which the parts of the wheel have to take, and the length of the elements. The parts of the nave of the wheel (Fig. 131) and the axle, which has to support the whole weight of the wheel, are made of walnut or mulberry because of their particular hardness and flexibility. They can last more than 20 years.\(^{321}\) Poplar, which is soft and easy workable, is employed to make the small parts of the wheel, like those which compose the rim.\(^{322}\) The spokes are also made of poplar because it provides long timbers and because there are numerous plantations of poplar in the area.\(^{323}\) The compartments are made of walnut or mulberry. Walnut is also used to make the dowels (Figs. 139, 139 and 140).

Although the wheels look rustic, they show a sophisticated construction, characterized by simple assembly and maintenance. The wheel is assembled on the floor (Figs. 135-137), while the final assembly is done at the place of

\(^{320}\) Mulberry also comes from plantations in the al-‘Alawîn mountains and poplar can come from plantations in the Euphrates valley.

\(^{321}\) It is possible to note that the nave and axle of the wheel are still in existence in some installations which were in use until the 1990s, like ziir al-‘Ašiq (Fig. 147) and al-‘Arza (Fig. 323).

\(^{322}\) The rim consists of many small elements connected by dowels. Rims are also made of walnut or mulberry.

\(^{323}\) Mulberry and poplar are grown specifically in plantations in Hamā to provide wood for the wheels. Mulberry and walnut also come from plantations around Damascus. Poplar also comes from Raqā, on the Euphrates valley, when a great quantity of it is needed.
installation and not in the yard. To understand the complexity of the design of the wheel we must consider three phases of construction:

First, the main structure is built. Four pairs of parallel beams perpendicular to each other are assembled. They will be connected to the central axle of the wheel when the wheel is installed in the channel.

Next, the inner rim and the secondary beams (i.e. the secondary spokes) are constructed and connected to each other by thin bars. The inner rim is always positioned at 2/3 the distance between the axle and the external rim of the wheel. The radial secondary beams stabilise the structure. Every beam consists of two parallel bars. The inner rim passes between them (Fig. 133). The beams are always installed in pairs in order to make the structure more stable.

Finally, two concentric external rims are mounted for the assembly of the compartments. The most external is built by connecting curved elements with a square section, creating the compartments. Several paddles connect the two external rims to each other (Figs. 133-134). Each compartment has an aperture for receiving water and a spout for pouring water into the channel of the aqueduct. To obtain a perfect circular wheel, the rims are built by connecting short elements using dowels.

The power of water on the paddles makes possible the rotation of the wheel. In order to exploit the flow of the river fully, some wheels have additional paddles which are mounted on the ends of the spokes and are employed during periods

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324 Each beam is composed of two parallel elements connected to each other by dowels.
of plentiful flow in order to turn the wheel more quickly. In order to raise more water some wheels can have additional compartments arranged on the external rim. When the level of water is higher than the normal level, it is possible, instead of opening the supplementary channels and the passages of water (to allow water to pass through in order to reduce the river level), to raise the wheel, increasing the thickness of the support of the wheel bearings, or to replace the wheel with another one with a smaller diameter.

There are differences in the diameter of the wheels. The size of the wheels ranges between 7 (al-Mu‘ayyadiyya) and 21.5 metres (al-Muhammadiyya). They can have 12 or 16 secondary beams on each side. Consequently they have 20 or 24 spokes on each side. The number of compartments and radial paddles ranges from 40 for small wheels, to 120 for big wheels.

The simple mechanism and assembly of the wheels make them easy to maintain, repair and reconstruct. The wood is not treated in any way. Continuous contact with the water makes it darker and slightly mossy and, particularly at dawn and sunset, the rays of the sun make the wheel glitter. Wooden wheels are not lubricated. The use of oil could provoke an excessive speed of the wheel which could cause parts to break or disconnect.

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325 Between November and March rains are frequent and the river reaches its height. So the best period for irrigation was April to October.
326 Wheels with additional compartments are, for instance, al-Dahsha (Fig. 292) and al-Shizar (Fig. 383).
327 However, by reducing the dimension of the wheel or raising the wheel, the aesthetic aspect and the geometric pattern of the front of the installation changes and loses symmetry and proportionality. The external rim of the wheel would not pass by the upper corners of the tower.
328 In fact the secondary beams add to the 8 spokes of the main beams.
329 A wheel has the same number of compartments and paddles, because they are fixed alternately to the external rims.
330 The lack of lubrication contributes to create the characteristic sound of the wheels during rotation.
5.1. VARIATIONS IN WHEEL CONSTRUCTION AND DESIGN

The geometric design which characterises the wheels is due to the disposition and number of the secondary beams and rims. As shown in Fig. 144, the hydraulic norias in the Mediterranean basin have beams which create geometric motifs. Western Syrian and Turkish wheels have a radial structure characterized by numerous spokes and one or two concentric rims. However, the radiality of the Orontes types can be defined as "polycentric", due to the position of the spokes which start from four centres (Fig. 132). Moroccan and some Spanish wheels have a polygonal structure characterized by an intersection of inscribed polygons which create star-shaped motifs. In Portugal and in Spain it is also possible to find combined radial and polygonal motifs, like the examples on the Genil river. At the bottom of the figure there are three reproductions of wheels which refer to the Spanish typology; they show a further variety of shapes, characterized by both radial and polygonal figures.

The radial wheels are characterized by two concentric rims with spokes, the number of which changes depending on the size of the wheel and the dimension of the spokes themselves. The shape of the East Asian wheels is radial. Compared to the radial wheels in the Mediterranean countries, the main difference lies in the number of spokes. In Asia they are considerably more numerous than in the Mediterranean wheels (Fig. 145). This is due to the necessity of strengthening the structure, because of the lightness and flexibility of the material employed (bamboo).

331 In Morocco, at Fes, only one big hydraulic compartmented noria has survived (Fig. 17).
332 This typology will be discussed in detail later in this chapter.
333 In Asian wheels the number of spokes ranges between 20 and 40.
As far as Syrian wheels are concerned, although their typology could seem less elaborate compared to the Spanish typology, their designs derive from a geometric composition which also creates star-shaped motifs. In fact a precise geometric construction is executed to obtain the structure of the wheel. In a wheel with 20 spokes, by connecting the ends of the spokes every 8 spans, we obtain 4 five-pointed stars. The intersections of these shapes are the points where secondary spokes are connected to the main beams (Fig. 146a). An analogous construction is done in a wheel with 24 spokes. By connecting the ends of the spokes every 10 spans, we obtain 2 twelve-pointed stars which determine the points of contact between main and secondary beams (Fig. 146b).

In both cases the secondary beams, as has been noted, are not precisely radial, because they do not start from the centre of the wheel, but from four centres equidistant from the circumference and from each other (Fig. 132). This position allows the best distribution of the internal forces involved. In fact, because the secondary beams create a natural brace to the main beams, the structure becomes less prone to warping and more resistant to forces of inertia and gravity and to hydraulic and transversal wind thrusts. This shows that structural, mechanical and aesthetic characteristics are successfully combined.

The possibility that Syrian wheels had a star-shaped design in the past is also supported by the possibility that Ta‘āsīf, the architect and astronomer who worked in Ḥamā in the early 12th century, could have designed the Orontes

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334 Replacing the secondary spokes, when it is necessary, is also easier than in wheels which have radial spokes.
wheels on the basis of his studies on the stars and celestial globes.\textsuperscript{335} Besides, the geometrical composition of wheels is emphasized by al-Ansārī in 1348 who includes \textit{lifting water} as one of the ten sciences derived from geometry.

"...From [geometry] ten sciences can be derived: architecture, optics, burning mirrors, centres of gravity, measuring and weighing, lifting water, lifting loads, clocks, war-machines and pneumatic apparatuses..."\textsuperscript{336}

Depending on the number of spokes and rims there are three main types of wheel.

The first type is that of a wheel with 20 spokes and internal and external rims. This type corresponds to a wheel with a short or medium diameter, between 7 and 13 metres. It can be seen, for instance, in the \textit{Gharbiyya} installation.

The second type has 24 spokes, internal and external rims and concerns the biggest wheels, with a diameter between 15 and 21.5 metres, such as \textit{al-Muhammadiyya}.

A third type is that of a wheel with 20 spokes and no internal rim. Only two wheels, \textit{al-Dahsha} and \textit{al-Qāq} at Ḥamā, have this unique shape which derives exactly from the geometric construction described above. This is probably the original Islamic shape. Except for these two examples, the wheels today on the Orontes have thinner external rims than in the past. Because of this they need the additional central rim to provide more stability and durability.\textsuperscript{337}

Although many installations no longer have a wheel, it is easy to understand the

\textsuperscript{335} For more information on Ta'lisīf see pp. 92-93.
\textsuperscript{336} Al-Ansārī (d. 1348) is cited in Hajjī Khalīfī’s work in 1657 (Hajjī Khalīfī 1835).
\textsuperscript{337} A sub-classification of the three types deals with the number of compartments. The wheels with internal and external rims and 20 spokes have 40, 60 or 80 compartments, those with internal and external rims and 24 spokes have 24, 48, 96 or 120 compartments, while wheels with no internal rim and 20 spokes have 60 or 80 compartments.
size of the wheel if the tower is preserved in good condition. As already noted, the external rim perfectly circumscribes the tower (Fig. 130). In addition, considering that the wheel with a diameter between 7 and 13 metres always has twenty spokes, and the bigger twenty-four spokes, it is possible to deduce how many spokes the wheel had.

6. OBSERVATIONS

During Roman times, probably since the 3rd century A.D., hydraulic norias started to be built. Because wood is a perishable material, the wheels have always had to be replaced periodically. The probable original shape is shown in the 5th-century Apamea mosaic. It was a perfect “radial” shape, characteristic of Roman wheels, as shown in other Roman sources. With the advent of Islam the shape of the wheel was definitively replaced by a new shape, probably from the 9th century, and from that period it has never changed. The new design has been transmitted generation to generation by the craftsmen, and today the Hamā governorate continues to built new wheels employing the same unique shape.

Some installations were entirely rebuilt in reinforced concrete in the first half of the 20th century, some of them being constructed on the remains of old installations in order to exploit the favourable topographical conditions of the area. Dams have been mainly reconstructed in concrete in the 20th century. The few remains of the original stone dams, however, do not provide enough evidence to understand if they were originally constructed when the aqueducts were built. However, we can suggest that dam and water passages were first constructed
when the new type of wheel was built, i.e. after the 9th century, because their main characteristic was to increase the river power into the main channel where the new stronger wheel was inserted.

7. HYDRAULIC NORIA IN EAST SYRIA

A small number of remains of hydraulic norias with pots have survived on the Khabūr and Euphrates rivers (Fig. 391). Only ruins of the masonry works survive, while all the wheels have disappeared.

On the low Khabūr they were numerous, due to its constant speed and flow of water and the fact that its banks are high enough to contain the slight floods.338 In the Syrian section they were concentrated between Sowār and Buṣayrā. According to the survey done by H. Charles in 1939 there were more than thirty installations,339 while today there are only a few remains of masonry works between Rāshda and al-Baghdādī, less than 5 km from the confluence of the Khabūr and Euphrates rivers.

On the Euphrates there are remains of the masonry works of three installations, one at Dayr al-Zūr, one near Dura Europos and one at Tall Hajīn (Fig. 394). Unlike the Orontes and Khabūr, the Euphrates has never had a large number of hydraulic norias because the period of maximum water supply does not correspond to the period of maximum demand. In fact in summer, when water is vital, the river is at its lowest, while late winter, when the water is not needed, is the period of maximum efficiency. In addition, the excessive raising of the water

339 Charles 1939, 48.
level when the river is in flood\textsuperscript{340} would destroy the structures because of their small size. The Euphrates is delimited by its high embankments which are prone to landslides. Another reason for the scarcity of hydraulic norias on the Euphrates is the fact that the water contains silt, which means it is not ideal for irrigation.

On both the Euphrates and Khabûr most installations were built on the same model which corresponds to that of the hydraulic norias along the river at ‘Āna (Fig. 14), in the river’s Iraqi valley.\textsuperscript{341} The masonry works are similar to the Orontes installations, i.e. the stone supports and the irrigation channels which run inland to water the fields. The stone support is rectangular\textsuperscript{342} instead of triangular, as in the Orontes installations. The wheel is different. It is smaller than those on the Orontes\textsuperscript{343} and there are pots instead of compartments. Pots are traditionally tied to the circumference of the wheel.\textsuperscript{344}

The secondary beams are perpendicular to the main beams. The wheel may seem rustic because of the irregular shape of the beams, which consist of trees which have not been shaped (Fig. 30). In these wheels the wood used is usually mulberry, which is easily available near the area.

The installation which has survived the longest is \textit{Ruwaishid}, on the low Khabûr. In 1936, it included three wheels (Fig. 392) which were still in use.\textsuperscript{345}

\begin{footnotesize}
\footnote{340}{The difference in river level between the maximum (between April and June) and the minimum (between January and March), can even reach 6 metres (Hruška 1995, 46).}
\footnote{341}{The different shape of the hydraulic noria at Tall Hajin was probably due to the large size of the wheel which was difficult to build without shaped timber.}
\footnote{342}{This may be explained by the fact that, due to the small size of the installations, steps on the sides of the wall are not necessary to reach the nave of the wheel.}
\footnote{343}{Girard \textit{et al.}, 1990, 380.}
\footnote{344}{Today the pots have been replaced by plastic or metallic buckets.}
\footnote{345}{Charles 1939, 47.}
\end{footnotesize}
One wheel survived until the end of the 1980s, when it was in working order, but not in use (Fig. 393). In the 1990s this last wheel disappeared. Only the remains of the masonry works have survived.

Like the Orontes installations, the hydraulic norias in East Syria have been gradually replaced by motor pumps starting from the 1960s. The last, Ruwaishid, was also replaced by motor pumps in the 1990s.

9. THE INSTALLATIONS IN USE IN OTHER PARTS OF THE WORLD: A COMPARISON WITH THE SYRIAN TYPOLOGY

Today the most significant hydraulic norias kept in working order are in Syria, East Asia and Central America (Figs. 18, 20, 21, 22). In East Asia water-wheels are especially common in China, in particular in the Guanxi region where they are still employed to irrigate large rice fields. In Central America they are mainly concentrated in Mexico, where there are some examples still in use, as on the Huitzilapan river.346

Only the Syrian devices have masonry works, while in Asia and America they have simple canalisations made of wood and a wheel which is fixed to the bed and to the banks of the river by poles. The installations are lighter than the Syrian ones. The central axle, made of a timber trunk, is supported by a wooden structure which lies on the bed and on the banks of the river.

346 Doolittle 1999, 10.
Unlike the Syrian installations, where the wheels are inserted in a canal to increase the speed of water, in Mexico (Fig. 24) and China the wheels are positioned along the river banks, without the possibility to modify the flow of the river itself to guarantee a constant rotation of the machine. The lack of stone walls on the sides of the wheel could be a disadvantage compared to Syrian machines where they guarantee protection and stability to the wheel. However the Chinese examples are often easily replaced and repaired due to their extremely simple assembly and the lightness and availability of the bamboo used in their construction. Because of its lightness, the structure can be moved to wherever it is needed along the river banks.

The Syrian installations are more efficient because they turn more quickly, as the speed of water is increased through the masonry works, which, consequently, enable a greater quantity of water to be raised. However, the scanty capacity of the aqueduct channel of the Chinese examples,\textsuperscript{347} is counterbalanced by the fact that the installations, being close to each other, raise the necessary quantity of water.\textsuperscript{348}

Syrian installations enable water to reach distant areas via a long aqueduct made of masonry, while Mexican and Chinese installations are employed to irrigate nearby fields and are constructed far from the towns. In Syria hydraulic norias are also built in the city to supply water to houses and public buildings.

In addition to the flexibility and lightness of the Chinese wheels, due to the characteristics of the bamboo (which is employed to make the whole structure), a

\textsuperscript{347} The aqueduct channel consists, in fact, of a simple bamboo cane (Fig. 20).

\textsuperscript{348} Two installations can be close to each other because of the slow river current. This would not be possible in Syria, because, as has been noted, two installations have to be distant enough to avoid the risk of turbulence which could interfere with the smooth running of the wheels.
further difference with the Syrian examples lies in the shape. The shape of the bamboo used to make the Chinese wheels is not altered. The spokes are not perpendicular to the horizontal axle of the wheel, but are considerably inclined (Fig. 21); this makes the lateral view of the wheels appear rhomboid in shape.

The Chinese water-wheels can reach a diameter of 23 metres; thus they slightly exceed the biggest Orontes wheels.

Because of their lightness, in China it is also possible to find a series of parallel wheels connected to each other by the same horizontal axle. In some cases, there are up to ten consecutive wheels.

It is interesting to note that in the Chinese wheels the bamboo pots, during the circular motion, gradually change position depending on the volume of water carried in the pot. In fact, at the river level, when they fill, due to the weight of water, they are in a vertical position, with the base at the bottom. Going up, between the river level and the top of the wheel, they are in an oblique position, which becomes horizontal at the top. Here, during the transfer of water to the irrigation channel, they are parallel to each other. Going down, between the top of the wheel and the river level, they are again oblique, but with the base at the top. At the river level they return to a vertical position due to gravity (Fig. 23).

Because of their light structure and the use of material easily available in the area, all three types of installation are well integrated into the landscape, where they appear part of the natural environment. However, while in China and

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349 The bamboo canes are not cut or shaped, but retain their natural appearance.
350 Needham and Ling 1965.
Mexico they have a movable structure, in Syria they are architectural constructions which are part of the surrounding lands and urban environment.
CHAPTER FIVE

SYRIAN SĀQIYA AND NORIA

1. INTRODUCTION

Water is easy to find underground in West Syria because of the permeable ground of the nearby mountains. In fact, in summer, the weather changes suddenly from a dry climate in the East to a Mediterranean climate, with heavy rains on the mountains in the West. The mountains of Lebanon, Anti-Lebanon, Jabal Zāwīya and Nuṣayrīya have a geological nature that is very permeable and supply water to underground reservoirs. These underground reservoirs are delimited by natural barrages made of the flows of lava of the Karkūr during the tertiary age or are natural depressions of the ground or natural basins excavated into those depressions. Reservoirs, depressions and basins hold rain water.

Numerous norias and sāqiya for raising underground water existed in western Syria. Today they have disappeared. As has been pointed out, sometimes they were associated with the fujjarāt, i.e. underground channels which carried water from a natural source to an underground basin. From there water was raised by a sāqiya or noria. Fujjarāt, like most qanawāt, are no longer in use owing to a drop in the water tables of these regions and to a lack of maintenance. They are

352 Of the machines which raised water from a river, only the “Muḥyī’l-Dīn Shaykh” sāqiya at Damascus has been preserved. It will be discussed later in this chapter.
353 As has been noted in Chapter Three, fujjarāt are slightly different from qanawāt, i.e. subterranean tunnels that tap the groundwater and lead the water to human settlements and agricultural lands using gravitational flow (pp. 97-98).
located throughout Syria, and examples may be found, for instance, at Palmyra, near Ḥamā, Dayr al-Zūr and Aleppo.\textsuperscript{354}

According to Schiøler, until the 1970s in this area there was a large number of norias. Many of these were in ruins and some were still in use.\textsuperscript{355} There were norias with a horizontal wheel with parallel cogs and a vertical wheel with a bucket chain, like the examples found at Ma'arrat al-Nu’mān (Fig. 399), and norias with a horizontal wheel with radial cogs and a vertical wheel with a chain with pots, as at Salḥīn (Fig. 400).

Another typology which existed in Syria is the sāqiya with a chain with pots and an elevated shaft, as shown by the only remains, which survived until the 1950s, of an installation found at Latakia (Fig. 401).\textsuperscript{356} It was used for raising water from underground.

In Damascus there is still a sāqiya which raised water from the Yazīd river, in the northern part of the city. It has been preserved in perfect condition and will be described later.

As described in Chapter Two, noria and sāqiya are moved by animal power and differ only in the position of the vertical wheels and in the length of the shaft which connects the two vertical wheels: a noria has a short shaft, while a sāqiya has a long shaft which can be close to the ground or elevated. For this reason the noria has both vertical wheels, that is the wheel with pots (or compartments) and

\begin{flushright}
\textsuperscript{354} Soumi & Aal Abdel 2004, 85. \\
\textsuperscript{355} Schiøler 1973, 22-24. \\
\textsuperscript{356} This survived until the 1950s when it was found and published by Nazim Moussly (Nazim Moussly 1950, 141-142). 
\end{flushright}
the wheel with cogs, inserted in the same cavity, while in the săqiya the vertical
wheels are separated and inserted in two different cavitys (Figs. 2, 7, 8).

The word săqiya derives from the Arabic word *saqa* which means "to
water", but, although it should indicate a "well", it is employed to indicate the
whole installation. The system is composed of two main parts, the wheels and
the masonry works which, when water is raised from underground, include a well
and one or two cavities. In the case of the installations which raise water from
underground, they can reach a depth of 20 metres. The wheels are mobile; the
secondary works are fixed. Although the wheels appear rustic, they have a quite
sophisticated construction.

2. MASONRY WORKS

Masonry works were built before the construction of the wheels. They included a
well, when water was underground, and one or two cavities (Fig. 402). To ensure
their impermeability, cavities and wells were made of brick. To understand the
design of the masonry works we can consider the following main phases of
construction.

First, a cylindrical well was excavated to a depth greater than the level of
water, in order to enable the chain of pots, which was subsequently inserted in the
well, to be submerged enough to raise water (Fig. 403). The base of the well

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357 Menassa & Laferrière 1975, 5.
consisted of a ring made of wood, with a diameter of about 3 metres, on which a brick wall was built (Fig. 404).  

Walls were built, at first, up to a height of about 3 metres. At this level, two parallel arches made of wood were inserted in the well and built on a pair of wooden or brick supports fixed in the wall. These arches served as supports to two transversal arches made of brick and were removed as the construction was completed (Fig. 403).

From the rectangular cross-arches a parallelepiped wall was built to ground level (Fig. 405).

Before arriving at the top, a corbel was inserted into the well to support the horizontal axle which connected the two vertical wheels (Fig. 2).

If the installation was a noria, only one excavation was done because both vertical wheels were inserted into it. If the installation was a saqiya, a second parallelepiped cavity was made to house the vertical cog-wheel.

An elevated circular track, on which animals walk around, was made of stone and brick and surrounded by a low wall made of earth. The track passed between the parallelepiped cavities.

3. THE WHEELS

Wheels and axes were made of wood, as well as the basin placed under the wheel which had to support the chain with pots. The basin received water poured

\[358\] The well is necessary only for installations raising water from underground. When water was raised from a river the chain with pots (or a compartmented wheel) was supported by a wooden system of poles which laid on the bed of the stream (Fig. 5) or was housed in a tower made of masonry (Fig. 9).
by the pots (Fig. 406). Hard wood resistant to water, like mulberry, was employed for the wheel which had to support the chain with pots, and for the horizontal axle. In fact both wheel and axle were always exposed to the water.

The phases of construction of the wooden parts were:

In the cavity for the wheel which had to support the chain with pots, the wooden basin was inserted to receive water poured by the pots.

A narrow parallelepiped underground passage was built under the track to enable the horizontal axle to pass through. This axle linked the vertical wheel with cogs and the vertical wheel with pots. The passage was covered by a small bridge made of earth consolidated by a timbering of trunks.

The vertical shaft was inserted in a hole in the ground. It had to support the horizontal cog-wheel. Two diametrically opposite stone pillars were built to support a big transversal bar which passed over the structure like a bridge and rested on the top of the vertical axle of the horizontal cog-wheel, to make the whole structure stable.

The wheel which had to support the chain with pots was then assembled. It consisted of two pairs of bars perpendicular to each other. There was a gap between the pairs of bars where the horizontal axle passed through to connect this wheel to the vertical wheel with cogs. Small transversal bars were inserted on the ends of this structure in order to support a chain with pots which consisted of two parallel cords on which pots were roped. Then the horizontal axle was positioned to link the vertical wheels (Figs. 407, 408 and 409).
Subsequently the vertical wheel with cogs was assembled. It had a diameter of about two metres. Cogs were inserted into equidistant holes made in the thickness of the rim. Subsequently four beams crossed the wheel leaving a square space in the middle to allow the horizontal axle to pass through. The wheel was placed in a specific rectangular cavity.

The horizontal wheel with cogs was also assembled. The disposition and installation of cogs were similar to the structure used for the vertical cog-wheel, but the horizontal wheel was crossed by two pairs of perpendicular beams. The beams left a space for the passage of the vertical axle in the centre (Fig. 2).

The vertical wheel with pots was inserted in the cavity and connected to the vertical cog-wheel through a horizontal axle. The connection of the vertical and horizontal cog-wheels allowed the rotation of both vertical wheels (Fig. 410).

The animal was connected to the axle of the horizontal wheel by a wooden bar which rested on its back. A cord was tied to another bar and created a sort of fork. For large machines, the conjunction between the two parts of the fork became a place for children\textsuperscript{359} to sit and drive the movement of the machine. When it was necessary to raise water from lower levels, because of the greater depth of water, two animals were employed.

The wheel with pots had to be changed periodically because the alternate humidity and dryness caused by an irregular use of the wheel led the wood to warp, when it was exposed to the water, and to crack when it was too dry. In addition, the transversal bars tended to get damaged owing to the weight of the pot-chain.

\textsuperscript{359} Children were usually employed for driving sāqiya because of their light weight.
4. THE MUḤYĪ’L-DĪN SĀQIYA AT DAMASCUS

At Damascus, in an alley in the area called "of the "Muḥyī’l-Dīn Shaykh ”, which is the extension of the popular Friday market, there is the so-called zuqāq al-nawā’īr ("lane of the norias") (Fig. 415), because of the number of norias and mills that used to line it. They raised water from the Yazīd river, which is a tributary of the Barada river which crosses Damascus. In the courtyard of one of the houses running alongside the alley, a single sāqiya with an elevated shaft has survived. It is a 13th-century machine which the inhabitants of the area call “Noria of al-Muḥyiddīn Shaykh”.

All the installations have always been state-owned, but built on private property that provided ideal locations for raising water from the river. Every installation provided water to the whole neighbourhood and every family had to pay attention to the device installed in its courtyard and keep it in working order. The norias were destroyed over time because of wars and earthquakes.

Al-Muḥyī’l-Dīn Shaykh sāqiya, which is located in a family courtyard house, is in a perfect state of preservation and was employed until about twenty years ago. Today it is still state property and kept in working order as a historical machine.

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360 Yusuf 1990, 184.
361 The area was founded by Muḥyī’l-Dīn Shaykh, a philosopher, who lived in the first half of the 13th century. According to the classification done in Chapter Two this machine is an animal-powered sāqiya with an elevated shaft.
362 Usually they were installed in the courtyard of private properties.
363 Roumi 1985, 54.
The design of this machine corresponds to one of those described in al-Jazari’s 1206 book on engineering. According to H. M. Yusuf it was designed by al-Jazari himself in the early 13th century, after having lived in the city of Diyarbakr, where he wrote his technical manuscript at the Artuqid court. The device was built for raising water up to the al-Qaimari hospital from the Yazid river. In fact water had to be very clean and the Yazid river, due to its altitude, was considered to be the cleanest tributary of the Barada. It would have been constructed about fifty years after al-Jazari’s death, i.e. in the second half of the 13th century. This is shown by the fact that the al-Qaimari hospital was inaugurated in 1254 by Sayf al-Din who had ordered its construction. Subsequently, when the Ottoman mosque close to the hospital was built, the machine was employed to supply water to the mosque itself. The pavement of the courtyard has an aperture which opens out to the Yazid river, which passes under the whole house. Over the aperture there is the tower which houses part of the machine (Figs. 416-436).

The drawings by al-Jazari are detailed and correspond to modern technical drawings (Figs. 411-413). The current of the Yazid river turns the twenty paddles of the vertical wheel. Through a horizontal axle the paddle wheel transmits the rotation to a vertical cog-wheel (likam) which is perpendicular to the horizontal cog-wheel (tabqq) which rotates along an extended vertical axle called sari. At the top, the sari is connected to another horizontal cog-wheel (tabqq) which turns

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364 It is the Al-jami’ bayn al-’ilm wa’l-’amal al-naﬁ’ fi sin’at al-hiyal (“A Compendium on the Theory and Practice of the Mechanical Arts”). This work has been discussed in Chapter Two (pp. 81-82).
365 Yusuf 1990, 184.
366 Roumi 1985, 54-55.
367 It is the Muhyi’l-Din mosque.
368 Yusuff 1990, 186-187.
a vertical wheel with parallel cogs (*laqqaṭa*). Through a horizontal axle the *laqqaṭa* turns a vertical wheel with parallel cogs which al-Jazari called *sindi*,\(^{369}\) that is a wheel which allows the rotation of the chain with buckets. The *sindi* is composed of two parallel rims connected to each other by a horizontal axle and a sequence of parallel horizontal cogs on which the bucket-chain rotates (axonometric detail in Fig. 411). A channel is installed between the two rims. Buckets go down to the river level to raise water and carry it to a height of 12 metres where it is poured into a channel in order to supply water to the house. The channel is also connected to an aqueduct to reach the mosque and the hospital, of which nowadays there is only the main façade. Round the *sindi* the bucket-chain consists of two steel chains on which buckets are fixed 60 centimetres apart. Through a 46-step winding staircase it is possible to reach the top tower from where there is a panoramic view of the area including the “Lane of the norias” and the Muhyi’l-Din Shaykh mosque (Figs. 415 and 416).

The only clear difference between this installation and that described by al-Jazari lies in the shape of the vertical wheel turned by the river. It is a paddle-wheel, while in al-Jazari’s drawings it is a scoop-wheel.

Although Yusuf has asserted that in al-Jazari’s drawings a wooden cow sculpture running the machine was represented for amusement,\(^{370}\) it is also

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\(^{369}\) The word *sindi* indicates that the provenance of this design of the wheel was Sind, the semi-arid region in the north-west of the Indian sub-continent. This area had been within the Arab sphere of influence for centuries; the first incursions are said to have occurred in the days of ‘Umar I, in the 7th century (al-Jazari 1974, 265).

\(^{370}\) Yusuf 1990, 187. It is possible that the book was intended as a practical guide to the construction of the automata which al-Jazari invented to amuse the Artuqid family (Ward 1985, 69).
possible that an animal was employed to boost the inadequate power of the river.\textsuperscript{371}

The machine, which has been restored by a project sponsored by Aleppo University in the 1980s, does not work any longer owing to the fact that the river water is not clean as in the past, and because water is now provided by the municipal aqueduct. However, because of its perfect state of preservation, it would be possible to reactivate it by re-installing the paddles which have been removed.

5. OBSERVATIONS

It is interesting to note that in Damascus there was once also a machine constructed as a piston pump, although nowadays there are no examples of it. In fact there is an al-Jazari drawing (Fig. 67) representing this machine which seems to have inspired some drawings done in Damascus by Taqī al-Dīn (Fig. 79) in his 1551 book on machines.\textsuperscript{372} In particular Taqī al-Dīn describes a pump very similar to that illustrated by al-Jazarī, except that it had a scoop-wheel instead of a paddle-wheel and the connecting rods were attached to an extension of the slot-rod. As is possible to see in the reconstruction of the al-Jazari drawing, the device is an absolutely ingenious piston pump (Fig. 414). A vertical paddle-wheel is moved by a stream. This wheel is connected to a vertical cog-wheel which transmits the rotation to a horizontal cog-wheel. Through a vertical peg the

\textsuperscript{371} The Yazid river, unlike the Orontes, did not have a strong current. Consequently the force of an animal might have been necessary to run the machine.

\textsuperscript{372} It is the \textit{al-Turuq al-saniyya fi alat al-ruhaniyya} manuscript ("The Sublime Methods of Spiritual machines"). It was written by Taqī al-Dīn in Damascus, where he spent most of his time after having lived in Turkey, his native country. This work has been discussed in Chapter Two (p. 84).
horizontal wheel is connected to a slot-rod which is pivoted at the end of the triangular box in which the pump is housed. The slot-rod is crossed by a transversal axle which supports two pistons on the sides. These pistons enter the two cylinders. At the end of each cylinder is a valve-box. A suction pipe passes through the valve-box and goes down to the water. When the slot-rod oscillates, one piston is on its suction stroke while the other is on its delivery stroke.

As already noted, the Muḥyīʾ-ʾl-Dīn Shāykh sāqiya has similarities with the Late Roman period sāqiya found at Formia in Italy (Figs. 105, 107 and 108)\textsuperscript{373} and it is possible that similar typologies entered Syria since Roman times. They could have had a bearing on the al-Jāzārī drawings, which, however, represent the first detailed description of a machine to raise water from a river through a system of perpendicular gears.

Unlike the hydraulic norias, for sāqiyas and norias there was no geometric construction pattern. This was due to the fact that the wheels of a sāqiya and noria did not have a real "elevation" because they were mainly hidden by the ground in which they were inserted or, as in the case of the zuqāq al-nawāʿīr in Damascus, they were built inside a private courtyard and only partially visible from the street. The typology of a Syrian sāqiya and noria, as shown by the Damascus example, must be appreciated for its sophisticated technological aspects.

Unlike the hydraulic norias, there are no significant variations in shape between the Syrian types and the installations in the other countries of the Mediterranean basin. Apart from the similarities between the Damascus and Formia sāqiyas

\textsuperscript{373} For a discussion of this issue see p. 97.
with an elevated horizontal axle, some similarities between Syrian and Spanish norias can be seen in the norias found at Ibiza (Fig. 7) and in the norias still in existence at Ma’arrat al-Nu‘mān and Salhīn until the 1970s (Figs. 10, 399 and 400).\textsuperscript{374}

\textsuperscript{374} According to Baroja, owing to the relationship between Syria and Spain in terms of irrigation systems during the Islamic empire, it is likely that the machine for raising water for irrigation arrived in Spain from Syria when the Muslims introduced their irrigation methods (Baroja 1954, 106).
CHAPTER SIX

PROGRESS, CHANGE AND SUSTAINABILITY

1. THE DECLINE OF SYRIAN WATER WHEELS: HYDRAULIC WORKS IN THE ORONTES VALLEY

Thanks to the introduction of new technologies based on oil or electricity, modern irrigation systems have replaced the old hydraulic works. Apart from water-wheels and the already mentioned qanawāt and fuţjarāt, the old hydraulic works included surface aqueducts or open channels,375 and three types of reservoir, i.e. ābār Rūmānī,376 birāk377 and khazzānāt.378

The use of water-wheels declined gradually in Syria. Saqiyas and norias were personal property and their use depended on the owners. The last saqiyas were in use until the 1980s, no longer for irrigation, but for raising water for domestic purposes. Subsequently their use declined further, with the introduction

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375 These aqueducts consist of carved stone canals to transport water from its source to a place where it was needed. Because gravity was the sole source of power conducting water, the source normally had to be higher than the city itself (Butcher 2003, 162). These channels were numerous in Southern Syria, like the examples at Tyre and Qalamun.
376 Ābār Rūmānī are parallelepiped wells dug underground. They have a narrow intake at the top. They are usually built on mountain slopes where small streams meet. The interior walls of the cisterns are often strengthened by an impermeable layer of cement, which is often smooth. Cisterns such as these are located throughout Syria, and examples may be found, for instance, at Homs, Hamah, Dayr al-zūr and Aleppo. Their size differs from place to place, and is often related to the nature of the area's rock formations. These wells are often in a poor state of repair due to the accumulation of deposits resulting from erosion (Soumi & Aal Abdel 2004, 82).
377 These cisterns are large water-storage tanks open to the sky into which rainwater is channelled (Butcher 2003, 166). The walls of these basins are constructed of smooth stones. In the middle of the construction is an elevated outlet (above the level of the pool bed), which allows water to be withdrawn and transported to villages and farms. This typology was widely used in southern Syria (Soumi & Aal Abdel 2004, 83). One of the best preserved birak is the birka al-Hajj at Bosra (Fig. 437).
378 These cisterns, locally called majahīr, are open, stone-walled reservoirs which receive water from nearby springs though channels dug under the surface of the ground. Built to provide water to both people and animals, these reservoirs are still in use today in Bosra al-Sham and Suwayda' (Soumi & Aal Abdel 2004, 84).
of water provision through pipes, faucets and pumps, so that many houses now have a direct water supply. Hydraulic norias started to disappear around the 1960s when landed properties increased in the Ḥamā area and when many hydraulic works started to be carried out in the Orontes valley. Landed properties started to develop in the second half of the 19th century. In fact, as has been pointed out, in the past the installations were state-owned. They supplied water to private properties nearby and, in return, land-owners had to take care of the installations. Citizens started to buy large landed properties which allowed cultivation of cereal and which were irrigated by the Orontes. Hydraulic norias declined because the properties started to employ electrical pumps to raise water in the 1960s. In addition, in the city of Ḥamā, a municipal aqueduct was built in the 1950s which supplied water to houses and public buildings.

Modern hydraulic works were carried out in order fully to exploit the area in terms of agriculture by regulating the flow of the Orontes, avoiding the winter floods and guaranteeing the quantity of water necessary for irrigation and the production of electrical energy. They include the construction of reservoirs created by new dams along the river, which normally fill during the winter and are used for irrigation in the summer, when the dam is opened, and water enters the river. In summer, when the river has been sufficiently filled by the reservoirs created by the dams, electrical pumps raise and pour water into a network of artificial canals to irrigate the fields. It is also possible to find modern hydraulic pumps for irrigation placed close to the old hydraulic norias in order better to

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379 Apart from summer, dams are also opened in other periods when there is little rain.
exploit the quantity of water available in the area. In some cases the old aqueduct channels are employed for carrying water raised by the pumps to the fields as, for instance, in zur abū Zayd and al-Kharīsa.

The first big hydraulic works were in South Ḫamā in the 1950s. Where the Orontes enters Syria, near the village of Riblah, five canals made of concrete were built for irrigation, connecting the river to the fields. Important works also included the barrage of the lake of Ḫoms in the Qaṭṭīna valley (Fig. 438) and a network of canals made of concrete. The barrage at Rastan is 20 kilometres north of Ḫoms (Figs. 439-440). It was built between 1958 and 1961. It is 56 metres high and 70 metres long and keeps 250 million m$^3$ of water.\textsuperscript{380} The construction of the Rastan dam, apart from creating a reservoir, caused a drop in water level which meant hydraulic norias were unable to work.

In North Ḫamā the most important hydraulic work was the so-called “project of the Ghāb” which started in 1953. It consisted of draining the plain where the river flowed, which, owing to a slight slope (0.10\%) of the Orontes in the al-'Ashārina area, did not provide a sufficient quantity of water to the surrounding territories. In 1968, when the plain was entirely drained, 11,000 families received lands from the Governorate\textsuperscript{381} in order to exploit the newly-created fields, which remained state property. To manage the irrigation works the families also had to work in cooperatives.\textsuperscript{382}

The Ghāb project has made a large area available for agriculture and new irrigation systems were accordingly developed. The works included barrages, a

\textsuperscript{380} Al-Dbiyat 1995, 108.
\textsuperscript{381} When the Ghāb was drained new fields were available.
\textsuperscript{382} Metral 1979, 316-317. To this day the irrigation network in most of Syria are managed by cooperatives, while land holdings tend to be very small.
network of canals for irrigation and canals for draining, at Maḥarda, al-
‘Ashārīna,\textsuperscript{383} and, more recently, at Zaizūn and Karkūr (Figs. 441-448). To raise 
water from the canals, electrical pumps are employed.

All the barrages are very big. The dam at Maḥarda, near Shīzar, was built in 1961. 
It is 40 metres high and 200 metres long and holds 65 million m\(^3\) of water.\textsuperscript{384} The 
dam at Zaizūn was built in the 1990s, 90 km north-west of Ḥamā. It is a large dam 
which holds rain-water and water coming from the nearby mountains. 
Unfortunately the Zaizun works were employed for ten years only because the 
dam collapsed in 2002 and has never been repaired. This collapse caused a flood 
of 70 million m\(^3\) of water which affected an estimated 60 square km area of the 
Ghāb. The impact of the released water caused serious damage in nearby 
populated area such as loss of houses, property, agricultural products, livestock 
and the death of 20 people.\textsuperscript{385} The dam built at Karkūr does not have a proper 
artificial basin, but bars the Orontes in order to keep more water in one part of the 
river and to supply water to the opposite section, when it is needed.

One of the main advantages derived from this project was that in the plain 
of Ghāb (which in the past was mainly covered by water) a construction of roads 
has been possible, thereby, improving the systems of communication. Another 
advantage was the extension of cultivatable fields. In addition, illnesses like 
malaria tended to decrease because there was no longer stagnant water.

\textsuperscript{383} al-Dbiyat 1995, 109-110. 
\textsuperscript{384} Metral 1979, 308-309. 
\textsuperscript{385} Sakharov et al. 2002, 2-4.
2. MANAGEMENT OF IRRIGATION SYSTEMS

Along the Orontes agriculture has always been the main economic resource for the population. Today agriculture employs about 40 percent of the active population in the Ḥamā district and 21.5 percent in that of Ḥoms. Surface irrigation is the prevailing system in Syria, covering 95 percent of the irrigated area. The average water consumption per hectare is very high. In fact in the Orontes area the consumption of water for irrigation is 9100 cubic metres per year.\textsuperscript{386} Although the hydraulic works in the Orontes valley have been able to regulate the flow of the Orontes, water resources are still limited compared to the needs of the country.\textsuperscript{387} To implement irrigation systems and cope with the increasing need for water, the Syrian government is defining several projects aimed at maintaining the old systems such as the ābār, which are considered to be one of the Syrian steppe’s main water resources,\textsuperscript{388} and implementing new projects in order to use surface runoff water and reduce the annual water consumption.\textsuperscript{389}

These projects could mainly consist of exploiting surface water coming from rivers and springs, through the installation of new devices such as sprinklers or drip irrigation and the construction of new line canals from the headwork to the farms. Underground water could be exploited by the rehabilitation and re-employment of old wells, in which measuring devices would be installed, and the water subsequently canalised to reach the fields for irrigation.

\textsuperscript{386} Varela and Sagardoy 2003, 340, 343.
\textsuperscript{387} Varela and Sagardoy 2003, 342.
\textsuperscript{388} Soumi and Abdel Aal 2004, 83. The new irrigation systems exploit surface water, coming from rivers and springs, while the old irrigation systems which are expected to be renovated exploit underground water.
\textsuperscript{389} Soumi and Abdel Aal 2004, 88.
Several assessments of Syrian irrigation systems show that it would be more economically and environmentally desirable to improve the efficiency of the existing systems than construct new ones.\textsuperscript{390}

3. SUSTAINABLE DEVELOPMENT OF WATER-WHEELS

Old irrigation systems which are expected to be re-employed in this initiative do not include water-wheels.\textsuperscript{391} If the status of water resources and the state of preservation of the structures determined the actual technical feasibility of hydraulic noria renovation, it would be possible to assess which installations could be developed as sustainable irrigation systems as well as attractions for the development of eco-tourism.\textsuperscript{392} In these circumstances hydraulic norias could be supplementary irrigation systems and provide significant environmental and economic advantages, as well as those of safety. As a clean technology they allow irrigation requiring no petrol or oil, but fully exploiting the power of the river. As an economical device they are built using materials found in the area and have a simple assembly. They are also efficient and have low operational and maintenance costs. Hydraulic norias do not present a risk of provoking heavy environmental damage, as happened at Zaizūn. Small floods cannot be dangerous. In fact the embankments where hydraulic norias are located always considerably exceed the river level in height.

\textsuperscript{390} Rosegrant 1997.
\textsuperscript{391} The wells belonging to old animal-powered machines have not been considered for rehabilitation. This is probably due to the fact that they provided a limited quantity of water compared to the other ancient water-harvesting systems, and were inserted into the ground and on the surface there is no evidence for their existence.
\textsuperscript{392} Town planning, engineering, and the status of water resources are important indicators for assessing which installations could be developed as an environmentally sustainable irrigation system.
On the other hand it is difficult to develop a basic recipe for renovating hydraulic norias in the Orontes valley. Re-employment would be difficult for several reasons. The big hydraulic works carried out in the Orontes valley have reduced the level of the river, making an eventual rehabilitation of hydraulic norias very difficult. In addition, owing to the large number of remains, it would require the mobilization of considerable manpower and expertise. When hydraulic norias stopped working and were subsequently abandoned for several years, most of them deteriorated considerably and many aqueducts collapsed.

A restoration aiming to re-activate the installations would involve reconstructing, in many cases, entire aqueducts or at least most of them. In addition, in some cases, restorations would be more difficult because new buildings have been erected on the foundations of the collapsed aqueduct, consequently obstructing its original course, as at al-Mamuriyya (Fig. 449), al-Wajiyad (Fig. 450) and al-Difa’i (Fig. 326). Consequently reconstruction would not be possible unless a specific project is planned.

Some aqueducts are in good enough condition to be re-employed for carrying irrigation water, mainly those restored in reinforced concrete between the 1930s and 1940s, as well as some examples of entirely new constructions from the same

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393 This is the case, for instance, for installations like zur al-Thalatha, Zur Traymisa, Tall ‘Ayyun and al-‘Asharina (Figs. 384-389) where in summer the bed of the river can dry up, as has been seen during the surveys done in summer/autumn 2004 and in spring/summer 2005.

394 As has been pointed out, restorations started in 1960, but only for the wooden parts. They were done by independent artisans to Governorate orders. Only in 1987 did a programme of complete restoration, which also included the masonry works, start. Between the 1960s and 1980s the programme of restoration and maintenance concerned only the wheels of the installations, while masonry works were mainly abandoned, falling gradually into disuse.

395 This happened when the installations stopped working between the 1950s and 1960s, and were consequently abandoned for several years. In particular, in al-Difa’i, new constructions have been built on the ancient mill connected to the installation, making it difficult to recognize its original aspect and shape (Fig. 325).

396 It would mean developing criteria involving the study of city planning, as well as expertise in various disciplines such as hydrology and engineering.
period. South of Ḥamā the aqueduct channels best preserved are those of al-ʿAšíq (Fig. 148), al-Shankiyya (Fig. 173), al-Jūmaqiyya (Fig. 165), al-Shahābiyya (Fig. 199), the group al-Dawwār and al-Sahiriyya (Fig. 213) and al-Jinān (Fig. 185), which is in good condition thanks to a recent restoration in stone. On the outskirts of Ḥamā, the al-ʿWaṭiyāt aqueduct channel has been restored and is employed to carry the river water poured into it by electrical pumps (Fig. 450). However, as mentioned above, the channel is interrupted by a house. The water carried by the aqueduct channel is employed for domestic purposes by the owners of the abutting house.

Al-Bishriyya al-Kubrā in Ḥamā, al-Jinān (Fig. 185) and al-Jūmaqiyya (Fig. 165 and 166), south of Ḥamā, preserve almost the entire structure, and most of it is original and in perfect condition. A rehabilitation of these installations for irrigation would seem less difficult than other cases, but it would require the reconstruction of the final part of the aqueducts which is lacking or in ruins. The hydraulic norias in the city have only the first arcades of the aqueduct which have been restored with stone and mortar (according to the original technique) while the remaining sector has disappeared and, in its place, there are constructions done between the 1960s and 1970s.

North of Ḥamā al-Ẓāhirīyya (Fig. 317), al-Mardisha (Figs. 335-337), zūr al-Ḥāmid (Figs. 355, 364), al-Nāṣiriyya (Fig. 365), zūr abū Zayd (Fig. 370) and Tall

397 Zūr abū Zayd is a further example where the aqueduct channel is employed to carry the water raised from the river by electrical pumps. Unlike al-Waṭiyāt, in this case the aqueduct channel is directed towards the fields to irrigate.

398 Al-Bishriyya al-Kubrā, in particular, was one of the installations which still worked for irrigation in the late 1980s, despite the increasing use of the electrical pumps which progressively replaced the hydraulic norias.
Ayyun (Fig. 388) preserve aqueduct channels in reinforced concrete in good condition which could easily be rehabilitated.

4. PRELIMINARY PROPOSAL FOR RENOVATING WATER-WHEELS

As has been shown, a re-employment of the hydraulic norias for their original purpose would present considerable difficulties. In addition it could diminish their cultural value as they could be seen mainly as utilitarian structures.

The material presented in this thesis shows that water-wheels in Syria, and particularly hydraulic norias, are sophisticated forms of construction that are a worthy part of Syria’s cultural and historical heritage. They are visually impressive devices, and have historical, environmental and iconographical importance. It has also been shown that the shapes of hydraulic norias are the results of an accurate and detailed design. Re-evaluating hydraulic norias in terms of historical heritage would make a great contribution to the knowledge and studies of water architecture in Syria and increase the awareness of the importance and beauty of these sites.

The actual in-progress programme of hydraulic noria restoration aims to preserve the installations individually. Most are far from the roads and usually there is no signpost to indicate their importance and beauty. Often hydraulic norias are not even visible from far away and it is necessary to walk through arduous paths to reach them. The majority of people, particularly foreign visitors, are aware of the existence of the installations in the city of Ḥamā and of some installations easily visible from the main road, like the two examples at Shīzar. In particular the
installations far from the city are often unknown even to local people. The Muḫyīʾl-Dīn Shaykh sæqiya in Damascus, which is actually maintained by the Department of Antiquities of Syria as an example of historical heritage, is mostly unknown even to the citizens of Damascus.

In museums or galleries there is a lack of visual public material, such as photographs, drawings and maps concerning Syrian water-wheels.

The actual programme of restoration could be integrated with a project of environmental design and exhibitions aimed at increasing the awareness of the historical and cultural value of these structures. Museums could be provided with illustrated and descriptive information about these old devices, hydraulic norias as well as sæqiyas and norias, and itineraries made available to reach the installations preserved in Syria, with an introduction to their most significant aspects. In this way people would make aware of this cultural heritage, and, depending on their interests, be able to choose which site to visit. The roads and paths could be signposted and improved by creating comfortable access through fields or plantations; a descriptive representation of the installations could be placed at the site to give information about the installation itself including historical and iconographical connections. For instance, for those which have a particular geometric elevation patterning, like *al-Mardisha* and *al-Qarnāṣiyya*, drawings and photographs could show how these installations could have originally been built and their links with Roman architecture, while for those like *Ghur al-ʿĀṣi*,

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399 The only public documents preserved in the new museum at Ḥamā related to water-wheels in Syria are the mosaic from Apamea (see pp. 90-91) and the reproductions of the drawings of *al-Muḥammadiyya* installation done by Ejnar Pugmann (see note 30 in Chapter One); there are some wooden models of the typology of the Orontes wheels, in the National Museum of Damascus (Figs. 451 and 452).
drawings and photographs could also show connections with the ancient construction techniques of Roman aqueducts.

The currently programme of restoration of the hydraulic norias in progress could consider maintaining not only those installations which are in better condition and easily visible and accessible from the main roads, but also the more isolated ones which, as has been shown, are among the most significant installations. In these sites new wheels could be installed for better appreciation of their spectacular aspects.

By combining the programme of maintenance and restoration with the kind of illustrative information explained above, a programme of re-evaluating Syrian water-wheels could be developed and their place established as a significant part of Syria’s architectural heritage.
CHAPTER SEVEN

SURVEY OF THE INSTALLATIONS
FOUND ON THE ORONTES RIVER

1. NOTES ON THE CENSUS

The census refers to the finding of installations along the Orontes and is mainly based on surveys carried out at the sites. The locations are shown in the enclosed map at the end of Volume Two and in Fig. 111. Installations are listed from south to north (Ḩoms to ‘Ashārina). Each entry includes a reference to pertinent photographs in Volume Two. The typology is based on findings and is classified according to the three schemes on the following page.
Schematic plans and axonometries showing the seven types of the Orontes installations.

Elevations of the five types of tower of the Orontes installations.

Elevations of the five types of aqueduct of the Orontes installations.
2. ENTRIES

1

name: Kafar Nāna
location: north of Ḥoms, between Ghajar Amīr and Kafar Nāna
typology: installation: type Al
tower: type A
aqueduct: type E
technique: reinforced concrete and basalt
findings: tower, triangle and aqueduct. The aqueduct is built in reinforced concrete (aqueduct channel and pillars) and basalt (to cover the pillars)
ote: it is one of the modern installations built between the 1940s and the 1950s. One hundred metres before the installation there are remains of an ancient mill. The tower aperture is rectangular in shape, unlike all the other installations on the Orontes.
photos: Figs. 114-115

2

name: zūr al-‘Āshiq
location: Rastan toward Ḥamā, zūr al-‘Āshiq
typology: installation: type Al
tower: type A
aqueduct: type A
technique: basalt and mortar; recent reconstructions in reinforced concrete
findings: aqueduct, tower and triangle and few remains of the dam. Tower and triangles are in basalt. The pillars of the aqueduct and the aqueduct channel are rebuilt in reinforced concrete. The pillars are covered with basalt. There are still remains of the dam and of the wooden spokes of the last wheel which existed until the 1990s. It had 24 spokes and 96 compartments.
ote: a mill in good state of preservation is in front of the installation. It was constructed in 1207/1853 by Aḥmad Ibn ‘Abd al-Walid al-‘Āshiq (al-Kilānī 1969, 96).
photos: Figs. 147-150
| 3 | name: Ghur al-'Asi | location: Rastan towards Hamā, Ghur al-'Asi |
|   | **typology:** installation: type A1 |
|   | tower: type A |
|   | aqueduct: type A |
|   | **technique:** limestone and mortar; recent reconstructions in basalt and reinforced concrete |
|   | **findings:** tower, remains of the two triangles, aqueduct and dam. The aqueduct channel has been reconstructed on a sequence of short pillars made of basalt which are in the place of the original aqueduct channel, of which some remains are preserved. |
|   | **note:** it shares the dam with Marīj al-dur which is on the opposite bank. In 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 111). |
|   | **photos:** Figs. 151-156 |

| 4 | name: Marīj al-dur | location: Rastan towards Ḥamā, Marīj al-dur |
|   | **typology:** installation: type C1 |
|   | tower: type B |
|   | aqueduct: type A |
|   | **technique:** basalt and mortar; recent restorations in concrete |
|   | **findings:** part of the aqueduct, the towers and remains of the triangles. The whole structure is made of basalt. Part of the aqueduct channel is rebuilt in concrete |
|   | **note:** It shares the dam with Ghur al-'Asi which is on the opposite bank. In 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 111). |
|   | **photos:** Figs. 151-152; 157-158 |
5

name: Qabibāt al-ʿĀṣi
location: Rastan towards Ḥamā, Qabibāt al-ʿĀṣi

typology: installation: type A
         tower: type A
         aqueduct: type E

technique: basalt and mortar. Probably the aqueduct and the pillars were in reinforced concrete covered with basalt, according to the technique adopted in the 20th century installations and because of the similarity with al-ʿĀṣila.

findings: tower and remains of the triangle, both in basalt. The aqueduct has entirely disappeared.

note: it is one of the modern installations built in the 1940s

photos: Figs. 159-160

6

name: zūr Abū Darda
location: Rastan towards Ḥamā, zūr Abū Darda

typology: installation: type A
         tower: type A
         aqueduct: type A

technique: limestone, basalt and mortar; reconstructions in reinforced concrete

findings: Remains of the tower, triangle, the first three arcades of the aqueduct and remains of the dam. Part of the aqueduct channel is rebuilt in reinforced concrete.

note: nearby numerous modern hydraulic pumps are installed because in this section of the valley the river current is particularly strong.

photos: Figs. 161-163
7

name: al-'Asīla
location: Rastan towards Ḥamā, zūr Abū Darda
typology: installation: type A1
tower: type A
aqueduct: type E
technique: basalt with mortar and reinforced concrete
findings: tower, triangle and aqueduct. Tower and triangle are in basalt, the pillars are in reinforced concrete covered with basalt, and the aqueduct channel is in reinforced concrete. On the aqueduct there is an inscription with the date 1356/1937 referring to the period of construction.
note: it is one of the modern 1930s installations
photos: Fig. 164

8

name: al-Jūmaqiyya
location: Rastan towards Ḥamā, al-Jūmaqiyya
typology: installation: type B1
tower: type A
aqueduct: type A
technique: basalt and mortar
findings: the bigger tower with its triangle and the two aqueducts are intact; there are remains of the smaller triangle and tower
note: it is the biggest installation and the best preserved in the valley, outside the city of Ḥamā
photos: Figs. 165-166
9
name: al-Mishyāh
location: Rastan towards Ḫamā, al-Mishyāh
typology: installation: type A1
tower: type A
aqueduct: type E
technique: basalt with mortar and reinforced concrete
findings: tower, remains of the triangle and dam, aqueduct. Triangle and tower are in basalt. The dam is made of stone. The pillars of the aqueduct are in reinforced concrete covered with basalt. The aqueduct channel is in reinforced concrete. On one side of the tower there is an inscription with the date of construction: “The installation was built by al-Barazi in 1353H”.
note: it is one of the modern 1930s installations
photos: Figs. 167-169

10
name: al-Shankiyya
location: Rastan towards Ḫamā, al-Shankiyya
typology: installation: type C2
tower: type A
aqueduct: there are no remains of the original aqueduct
technique: limestone, basalt and mortar; reconstructions in reinforced concrete
findings: of the original structure only remains of the dam and the triangles (foundations) are preserved. They are made of stone. The new construction includes one tower, one triangle made of limestone, and the aqueduct in reinforced concrete with pillars covered with basalt.
note: it was rebuilt on the remains of an old installation which has disappeared.
photos: Figs. 170-173
11
name: *al-Taqsīs*
llocation: Rastan towards Ḫamā, zūr al-Taqsīs
typology: installation: type A2
tower: type B
aqueduct: type A
technique: limestone and mortar
findings: tower, aqueduct, the two triangles and remains of the dam. The whole structure is well preserved and there is no evidence of restoration
note: in 981/1573 it was mentioned in the court logbook (al-Kīlānī 1969, 96)
photos: Figs. 174-176

12
name: *al-Ramlīyya*
llocation: Rastan towards Ḫamā
typology: installation: no recognizable
tower: no recognizable
aqueduct: there are no remains of the original aqueduct
technique: not recognizable because of the lack of original remains
findings: there are no remains of the original structure, only four pillars and part of the aqueduct channel in reinforced concrete, belonging to a 20th-century reconstruction
note: it was rebuilt on the remains of an old installation.
Modern electrical pumps are installed nearby.
photos: Fig. 177
13

name: al-Jarniyaa
location: Rastan towards Ḥamā, al-Jarniyaa
typology: installation: type A2
tower: type C
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: tower, an entire triangle and remains (foundation) of the second triangle. Dam and supplementary channels are rebuilt in reinforced concrete. The tower has two levels of apertures asymmetrical to each other. On the second level there was also a rectangular aperture subsequently closed.
note: in 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 112)
photos: Figs. 178-181

14

name: zūr al-Sūs
location: Rastan towards Ḥamā, zur al-Sūs
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone, basalt and mortar; some restorations in reinforced concrete at the top of the tower
findings: tower and part of the aqueduct
The triangle is almost entirely destroyed.
photos: Figs. 182-183

15

name: al-Qraymish
location: Rastan towards Ḥamā, Shaikh Abdallah
typology: installation: no recognizable
tower: type A
aqueduct: no remains
technique: limestone and mortar
findings: remains of the tower only
notes: the lack of remains of a triangle does not allow an exact classification (type A1 or A2)
photos: Fig. 184
16

name: *al-Jinān*
location: Rastan towards Ḥamā, al-Jinān
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; recently reconstructions in reinforced concrete
findings: tower, aqueduct, triangle, dam.
All parts are in perfect condition.
notes: A mill is connected with the installation.
The installation was in operation till the 1990s. The wheel had 24 spokes, 120 compartments, a diameter of 16 metres.
photos: Figs. 185-189

17

name: *al-Murādiyya*
location: Rastan towards Ḥamā, al-Murādiyya
typology: installation: type A2
tower: type A
aqueduct: there are no remains of the original aqueduct
technique: limestone, basalt and mortar
findings: remains of the tower and dam; foundations of the triangles
note: modern hydraulic pumps have been installed close to the old installation.
note: in 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 112)
photos: Figs. 190-191
name: al-Ra'būn
location: Rastan towards Ḫamā, al-Ra'būn
typology: installation: type A1
tower: type A
aqueduct: there are no remains of the original aqueduct

technique: limestone and mortar; reconstructions in reinforced concrete and blocks of cement

findings: of the original structure made of stone and mortar, there is the dam and remains of the foundations of the tower and aqueduct. The new tower and aqueduct are rebuilt in reinforced concrete. The new triangle is in limestone and mortar.

note: a mill is connected to the installation. The last wheel worked until the 1990s (it had 24 spokes, 72 compartments and 36 additional compartments). Hydraulic noria and mill were mentioned in the court logbook in 971/1563 (Zaqzouq 1990, 350).

photos: Figs. 192-195

name: al-Šārmiyya
location: Rastan towards Ḫamā, Srāyḥīn
typology: installation: type A2
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete

findings: tower, remains of the triangles and part of the aqueduct whose channel is rebuilt in reinforced concrete

photos: Figs. 196-197
20
name: *al-Shahābiyya*
location: Rastan towards Ḥamā, Srayḥīn
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; recent reconstructions in basalt and reinforced concrete
findings: tower, triangle and part of the aqueduct. The aqueduct channel is rebuilt in reinforced concrete, the pillars are rebuilt in reinforced concrete covered with basalt
note: it is one hundred metres from *zūr Sreḥīn*
photos: Figs. 198-199

21
name: *zūr Sreḥīn*
location: Rastan towards Ḥamā, Srayḥīn
typology: installation: type A1
tower: type A
aqueduct: no remains
technique: limestone and mortar
findings: remains of the tower and dam. A recent aqueduct channel in reinforced concrete has been built at the same level as the new dam rebuilt in concrete on the remains of the original dam.
note: modern hydraulic pumps are installed nearby. It is one hundred metres from *al-Shahābiyya.*
photos: Figs. 200-201

22
name: *al-Qabaliyya*
location: Rastan towards Ḥamā, Srayḥīn
typology: installation: type A2
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: tower, remains of the base of the aqueduct. The triangle has been rebuilt in reinforced concrete
photos: Figs. 202-203
23

name: al-Kharīsa
location: Rastan towards Ḫamā, on the southern outskirts of Ḫamā

typology: installation: type A1
tower: type A
aqueduct: type A

 technique: limestone and mortar; reconstructions in reinforced concrete

findings: tower, remains of the aqueduct and triangle. The tower has the upper part rebuilt in reinforced concrete, like the base of the triangle and the new aqueduct channel.

note: in 971/1563 it was mentioned in the court logbook (Zaqzouq 1990, 349). The governorate expects to install a new wheel in 2005/2006. The aqueduct channel is employed to carry the river water. The water is raised by electrical pumps and poured into the aqueduct channel.

photos: Figs. 204-207

24

name: al-Jāiyya
location: Rastan towards Ḫamā, Srayḥīn

typology: installation: type A2
tower: type A
aqueduct: there are no remains of the original aqueduct

 technique: limestone and mortar; reconstructions in reinforced concrete

findings: Of the original structure only remains of the bases of the tower and triangles are preserved. The aqueduct and the upper part of the tower are rebuilt in reinforced concrete. The upper parts of the triangles are rebuilt in concrete.

note: In 971/1563 it was mentioned in the court logbook (Zaqzouq 1990, 349).

photos: Fig. 208
name: al-Zirkadāsh and al-Wajiyyāt
location: Rastan towards Ḥamā, Srayḥīn
typology: installation: type B1
tower: type A
aqueduct: type A
technique: limestone, basalt and mortar; reconstructions in reinforced concrete
findings: The bigger (al-Wajiyyāt): tower, triangle, aqueduct partially rebuilt in reinforced concrete (aqueduct channel and pillars) and stone (to cover the pillars in reinforced concrete).
The smaller (al-Zirkadāsh): aqueduct, tower and triangle
note: al-Wajiyyāt shows the typical stepped corbels in perfect condition
photos: 209-212

name: al-Dawwār and al-Sahiriyya
location: southern Ḥamā
typology: installation: type B3
tower: type A
aqueduct: type A
technique: limestone, basalt and mortar; reconstructions in reinforced concrete
findings: The bigger (al-Sahiriyya): tower, the two triangles, aqueduct. The aqueduct channel is rebuilt in reinforced concrete.
The smaller (al-Dawwār): tower, aqueduct, and one triangle. The aqueduct channel is rebuilt in reinforced concrete. The wheel is preserved but not in use. It has 20 spokes and 80 compartments.
The triangles have been restored in concrete
note: hydraulic modern pumps are installed nearby. The existing wheel is expected to be restored in 2005/2006.
In 1309/1891 it was mentioned in the account book of waqf of Nashu Basha (Zaqzouq 1990, 347).
photos: Figs. 213-218
name: al-Jahidiyya and al-Qarnasiyya
location: southern outskirts of Ḥamā

typology: installation: type B1
tower: type A
aqueducts: type D and type A

technique: limestone, basalt and mortar; reconstructions in reinforced concrete

findings: The bigger (al-Qarnasiyya): tower, triangle, part of the aqueduct. The aqueduct is 300 metres long and has the upper part partially collapsed.
The smaller (al-Jahidiyya): tower, triangle, remains of the aqueduct which has the upper part rebuilt in reinforced concrete and blocks of cement. It shares the dam with al-Bunduqiyaa which is on the opposite bank.

photos: Figs. 219-224

name: al-Bunduqiyaa
location: southern outskirts of Ḥamā of Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete

findings: remains of wall in stone and mortar, part of the new aqueduct channel and some pillars rebuilt in reinforced concrete, tower completely rebuilt in reinforced concrete. The nave of the wall of the aqueduct clearly shows the original technique (coursed rubble masonry facing of small squared blocks).

note: it shares the dam with al-Jahidiyya and al-Qarnasiyya which are on the opposite bank.

In 790/1388 it was mentioned in the waqfiya of Bard al-Din Hasan (Zaqzouq 1990, 348).

photos: Figs. 225-226
29

name: Marta' bānī
location: southern Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete

findings: tower in perfect condition with the upper part in reinforced concrete, triangle in perfect condition and remains of the aqueduct. It shared the dam with al-Sakhrīyya, of which only a few stones of the tower remain, on the opposite bank.

note: in 970/1562 it was mentioned in the court logbook

photos: Figs. 227

30

name: al-Jadīda
location: southern Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete

findings: triangle, tower destroyed in the upper part, part of the aqueduct mainly rebuilt in reinforced concrete. Part of the aqueduct still has the original arches.

note: it is located opposite ‘Antar and ‘Abla.

photos: Fig. 228

31

name: ‘Antar and ‘Abla
location: southern Ḥamā

typology: installation: type C1
tower: type B
aqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete

findings: the two towers, remains of the two triangles and the aqueduct whose upper part is rebuilt in reinforced concrete.

note: it is located opposite al-Jadīda

photos: Fig. 229
name: al-Bishriyyat
location: Ḥamā
typology: group a): installation: type B1
tower: type E
aqueducts: type A and B
group b): installation: type A2
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: Group a): aqueducts, towers, triangles and wheels. The aqueducts have the final parts in reinforced concrete.
Group b): tower, triangles, wheels and remains of two arcades about one hundred metres from the wheels.
The four wheels are in use:
Group a): the biggest wheel has 24 spokes and a diameter of 18 metres; the smallest has 20 spokes and a diameter of 10 metres
Group b) The twin wheels have 20 spokes and a diameter of about 8 metres.
note: the two groups are located on both ends of the same dam.
1970s constructions were built on the foundations of the collapsed aqueduct of the twin installation (group b) obstructing its original course
Group a) was in use in the 8th/14th century for irrigation, to supply water to the Taqi al-Din hammam (al-Kīlānī 1969, 91).
The biggest hydraulic noria of group a) (al-Bishriyya al Kubrā) was in use for irrigation until the 1980s.
photos: Figs. 230-239
name: al-Jisriyya
location: Ḥamā

typology:
installation: type A1
    tower: type A
daqueduct: type A

technique: limestone and mortar; reconstructions in reinforced concrete
findings: the entire installation apart from the final part of the aqueduct.
The wheel is in use. It has 24 spokes, 96 compartments and a diameter of 14 meters.

note: It supplied water to the nearby hammam where there are still remains of the aqueduct channel. The reconstruction of the first seven stone arcades of the aqueduct is expected in 2005/2006.

Today the aqueduct channel is employed to carry water to the artificial lake of a nearby public garden.
In 975/1567 it was mentioned in the court logbook (Zaqzouq 1990, 340).

photos: Figs. 13; 131; 240-248

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name: al-Ma’mūriyya
location: Ḥamā

typology:
installation: type A1
    tower: type D
daqueduct: type B

 technique: limestone and mortar
findings: the entire installation apart from the final part of the aqueduct. On the aqueduct there is an inscription referring to the probable reconstruction of the installation: “Balbak prince of Ḥamā has ordered the construction of this noria and its channel in 857H/1453”.

The wheel is in use. It has 24 spokes, 120 compartments and a diameter of 21 metres.

note: apart from irrigation it supplied water to eight mosques, four hammams and 250 domestic cisterns (Delpech et al. 1997).

It still supplies water to the fountain in the courtyard of the al-Azem palace (the old Hamā museum).

It is the second largest installation in the Orontes valley, after al-Muḥammadiyya.

photos: Figs. 247-248; 254-259.
35

name: al-Mu'ayyadiyya
location: Hamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar

findings: remains of triangle, the entire tower and the wheel rebuilt in 1979. The wheel is in use. It has 20 spokes, 49 compartments and a diameter of 7 metres.

note: it is a few metres from al-Ma'mūriyya and al-'Uthmāniyyatān. Apart from irrigation, it supplied water to the near al-Khankah mosque (Zaqzouq 1990, 341).

photos: Figs. 252-253

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36

name: al-'Uthmāniyyatān
location: Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar

findings: remains of triangle, tower and wheel rebuilt in 1980. The wheel is in use. It has 20 spokes, 60 compartments and a diameter of 12 metres.

note: it is a few metres from al-Ma'mūriyya and al-Mu'ayyadiyya. Apart from irrigation, it supplied water to the near al-Khankah mosque (Zaqzouq 1990, 341).

photos: Figs. 126; 249-251
name: al-Gharbiyya, al-Ṣahyuniyya and al-Rawaniyya

location: Hamā, opposite al-Kilāniyya

typology: installation: type B2
tower: type A and B
aqueduct: type A

technique: limestone and mortar

findings: dam, the three triangles, the two towers and the three wheels.
The three wheels are in use:
The twin wheels: Al-Ṣahyuniyya and al-Gharbiyya: 24 spokes, a diameter of 17 metres;
Al-Rawaniyya: 20 spokes, a diameter of 10 metres.

note: the group shares the dam with al-Kilāniyya which is on the opposite bank.
Al-Rawaniyya (named after the architect who did the design) was added to the group in 1990. The two biggest wheels have slightly different diameters (al-Gharbiyya is slightly bigger than al-Ṣahyuniyya)

photos: Figs. 260-265

38

name: al-Kilāniyya

location: Ḥamā, opposite the group al-Gharbiyya, al-Ṣahyuniyya and al-Rawaniyya

typology: installation: type A1
tower: type A
aqueduct: there are no remains of the aqueduct

technique: limestone and mortar

The wheel is in use. It has 20 spokes, 80 compartments, 11 additional compartments and a diameter of 13 metres.
findings: tower, triangle, dam and wheel.
The wheel is in use. It has 20 spokes, 80 compartments, 11 additional compartments and a diameter of 13 metres.

note: it was originally located on the façade of the al-Kilāni palace, destroyed in 1982.
It shares the dam with al-Gharbiyya, al-Ṣahyuniyya and al-Rawaniyya.
In 1138/1725 it was mentioned in the waqfiya of Yasin Kilani (Zaqzouq 1990, 342).

photos: Figs. 263, 266-272
name: *al-Khudūra* and *al-Dawālīk*
location: Ḥamā

typology:
- installation: type B1
- tower: type A
- aqueduct: type A

technique: limestone and basalt with mortar

findings: triangles, towers, the first section of the aqueduct of *al-Khudūra*, dam and wheels.
The wheels are in use. *Al-Khudūra* (the biggest) has 24 spokes, 96 compartments and a diameter of 17.5 metres. *Al-Dawālīk* (the smallest) has 20 spokes and a diameter of 13 metres.

note: It shares the dam with *al-Dahsha* which is on the opposite bank. A mill is connected to the installation. The aqueduct of *al-Dawālīk* installation has completely disappeared. *Al-Dawālīk* wheel was restored in Autumn 2004.

In 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 110).

photos: Figs. 273-278; 281-289

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name: *al-Dahsha*
location: Ḥamā

typology:
- installation: type A1
- tower: type A
- aqueduct: type A

findings: tower, wheel, part of the triangle and the first section of the aqueduct whose channel is rebuilt in concrete.

technique: limestone and mortar; reconstructions in reinforced concrete.
The wheel is in use. It has 20 spokes and 60 compartments. The wheel has no internal rim.

note: It shares the dam with *al-Dawālīk* and *al-Khudūra* which are on the opposite bank. The aqueduct channel is employed to carry the river water which enters the channel by electrical pumps.

In 973/1566 it was mentioned in the court logbook (Zaqzouq 1990, 344).

photos: Figs. 279-280, 290-293
name: al-Muḥammadiyya
location: Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstruction in reinforced concrete

findings: tower, triangle, the first 15 arcades of the aqueduct and dam. The aqueduct is mainly rebuilt in reinforced concrete covered with limestone and basalt. The wheel is in use. It has 24 spokes, 120 compartments and a diameter of 21.5 metres.

note: on the thirteenth arch there is an inscription referring to the probable reconstruction of the installation: “This big and blessed water-wheel was constructed...in the days of our Lord, His Most Noble Excellency Saif al-dīn Tanyaraq, Viceroy of the province of Ḥamā, during the last days of the year 763” (October 1362).
Apart from irrigation, it supplied water to the Great mosque, the al-Dahab hammam, nearby houses and fountains. Nearby there are three mills in perfect condition.
It shares the dam with al-Qāq which is on the opposite bank.
It is the biggest hydraulic noria in the Orontes valley.

photos: Figs. 294-302
42
name: al-Qāq
location: Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar; reconstruction in reinforced concrete

findings: tower, triangle, wheel, dam and remains of the aqueduct which are mainly rebuilt in reinforced concrete
The wheel is in use. It has 20 spokes. It does not have an internal rim.

note: a mill is on the opposite end of the dam. It shares the dam with al-Muḥammadiyya which is on the opposite bank.
In 1311/1893 it was mentioned in the book of accounts of the waqf of Nasuh Basha (Zaqzouq 1990, 345).

photos: Figs. 303-304

43
name: al-Jawhariyya
location: Ḥamā towards ‘Ashārīna, on outskirts of Ḥamā

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar

findings: tower, triangle, wheel, remains of the first two arcades of the aqueduct and dam.
The wheel is in use. It has 24 spokes.

note: modern hydraulic pumps are installed nearby. It shares the dam with al-Zārūb which is on the opposite bank.

photos: Figs. 307-311
44  
name: al-Zārūb  
location: Ḥamā towards ‘Ashārīna, on outskirts of Ḥamā  
typology: installation: no recognizable  
tower: type A  
aqueduct: there are no remains of the original aqueduct  
technique: limestone and mortar; reconstructions in reinforced concrete  
findings: remains of the reconstruction of the tower in basalt and limestone and of the aqueduct in reinforced concrete whose pillars are covered by stone.  
note: It shares a dam with al-Jawhāriyya which is on the opposite bank.  
photos: Fig. 312

45  
name: Kazo al-Kabīra  
location: Ḥamā towards ‘Ashārīna, Kazo  
typology: installation: type A1  
tower: type A  
aqueduct: type A  
technique: limestone and mortar; reconstructions in reinforced concrete covered by basalt and limestone  
findings: of the original structure remains of the bases of the triangle, dam and tower are preserved. Triangle and tower are rebuilt in reinforced concrete. The aqueduct is rebuilt in reinforced concrete and covered with basalt stone.  
note: a mill is connected to the installation. In 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 117).  
photos: Figs. 313-315
name: *al-Zāhiriyā*

**location:** ʿĀshārīnā, on the outskirts of Ḥamā

**typology:**
- installation: type A1
- tower: type A
- aqueduct: type A

**technique:** limestone and mortar; reconstructions in reinforced concrete

**findings:** triangle, tower, aqueduct. The upper part of the tower is in concrete and blocks of cement. The first six arcades are preserved. The following part of the aqueduct and the aqueduct channel are in reinforced concrete.

**note:** it shares the dam with *Kazo al-Sajira* which is on the opposite bank. The governorate expects to install a new wheel in 2005/2006. The previous wheel was in use until the late 1990s.

**photos:** Figs. 316-317

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name: *Kazo al-Sajira*

**location:** ʿĀshārīnā, on the outskirts of Ḥamā

**typology:**
- installation: type A1
- tower: type A
- aqueduct: type A

**technique:** limestone and basalt with mortar; reconstructions in reinforced concrete

**findings:** tower, triangle and five arcades of the aqueduct. Part of the aqueduct channel is rebuilt in reinforced concrete.

**notes:** it shares the dam with *al-Zāhiriyā* which is on the opposite bank.

**photos:** Figs. 318-322
48

name: al-Difā‘ī
location: Ḥamā towards ‘Ashārīna
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and basalt with mortar; reconstructions in blocks of cement
findings: remains of the triangle and tower. The central window has been wallet up.
note: a mill is connected to the installation. It was mentioned in the waqfiya of Yasin Kilani in 972/1561 (Zaqzouq 1990, 353).
photos: Figs. 325-326

49

name: Al-Arza
location: Ḥamā towards ‘Ashārīna
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar
findings: tower, triangle, aqueduct. There are still remains of the wooden spokes of the last wheel which existed until the 1990s. The wheel had 24 spokes, 96 compartments, 24 additional compartments and a diameter of 15 metres.
photos: Figs. 323-324
note: the tower preserves the stepped corbels typical of the Orontes installations. In 971/1560 it was mentioned in the court logbook (Zaqzouq 1990, 353).

50

name: al-Qusaiyya
location: Ḥamā towards ‘Ashārīna
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar
findings: remains of the triangle, tower and dam.
photos: Fig. 327
51
name: al-Maristān
location: Ḥamā towards ʿAshārina, al-Maristān
typology: installation: type A1
tower: type B
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: remains of tower, triangle and aqueduct. The upper part of the tower is rebuilt in reinforced concrete, but has partially collapsed. The pillars of the aqueduct are rebuilt in reinforced concrete; some of them are covered with stone. The aqueduct channel is rebuilt in reinforced concrete.
note: modern hydraulic pumps are installed nearby.
photos: Figs. 328-331

52
name: al-Mardīsha
location: Ḥamā towards ʿAshārina, al-Mardīsha
typology: installation: type A1
tower: type B
aqueduct: type C
 technique: limestone and mortar; reconstructions in reinforced concrete
findings: triangle, tower, the first section of the aqueduct and remains of the dam. Most of the aqueduct and the aqueduct channel are rebuilt in reinforced concrete.
note: It was in use until 1975. In 971/1560 it was mentioned in the court logbook (Zaqzouq 1990, 153).
photos: Figs. 332-337
53

name: al-Kharbāna

location: Ḥamā towards ʿAshārina, zūr Flayfīla

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar

findings: tower and triangle

note: The remains are all original, made of limestone and mortar. Although no traces of the aqueduct remain, because of the small size of the tower and of the steep slope of the ground, the ideal aqueduct would have been type A.

photos: Figs. 338-341

54

name: al-Murtaqab

location: Ḥamā towards ʿAshārina

typology: installation: type C1
tower: type A
aqueduct: type A

 technique: limestone and basalt with mortar; reconstructions in reinforced concrete

findings: the two towers, remains of the two triangles, aqueduct and dam. The two towers are connected to each other by a recent aqueduct channel in reinforced concrete and were restored with concrete, basalt and limestone.

note: There are modern hydraulic pumps nearby.

In 927/1520 it was mentioned in the waqfiya of Murad Efendi (Kamel 1974, 110).

photos: Figs. 342-346
55
name: al-Bilhusayn
location: Ḥamā towards ‘Ashārina, Bilhusayn
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: the tower, remains of the wheel and foundation of the aqueduct. The upper part of the tower is in reinforced concrete.
note: It is very close to al-Murtaqab, on the same bank. There are modern hydraulic pumps nearby.
photos: Fig. 347

56
name: zūr al-Jadid
location: Ḥamā towards ‘Ashārina, zūr al-Jadid
typology: installation: type A2
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: remains of the triangles, towers, dam and aqueduct. Aqueduct: near the tower there are remains of the reconstruction in reinforced concrete. The following part of the aqueduct is original, made of stone. Modern pumps are placed near the installation.
photos: Figs. 348-350

57
name: al-Khattāb
location: Hamā towards ‘Ashārina, al-Khattāb
typology: installation: type C2
tower: type C
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: remains of the triangles, two towers and aqueduct. The pillars of the aqueduct are reinforced with basalt.
note: it is closed to zūr al-Jadid, on the same bank.
photos: Figs. 351-354
name: zur al-Ḥāmīd
location: ʿHamā towards ʿAshārina, zur al-Ḥāmīd
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: tower, triangle aqueduct and a few remains of the dam. The pillars of the aqueduct are rebuilt in reinforced concrete covered with basalt. The triangle is partially rebuilt in concrete
note: it shares a dam with al-Masāliq which is on the opposite bank.
photos: Figs. 355, 358; 360-364a

name: al-Masāliq
location: ʿHamā towards ʿAshārina, zur al-Ḥāmīd
typology: installation: type A2
tower: type A
aqueduct: type A
 technique: limestone and mortar; reconstructions in reinforced concrete
findings: tower, triangles, part of the aqueduct and a few remains of the dam. The pillars of the aqueduct are rebuilt in reinforced concrete covered with basalt.
note: it shares the dam with al-Ḥāmīd which is on the opposite bank.
photos: Figs. 355-360; 364a
60

name: al-Nāsiriyā
location: Ḥamā towards ‘Ashārīna,
al-Nāsiriyā

typology: installation: type A2
tower: type A
aqueduct: type A

technique: limestone and mortar;
reconstructions in reinforced concrete

findings: Of the original structure only
remains of the triangles (foundations) are
preserved. They are made of stone and
mortar. The whole structure is rebuilt in
reinforced concrete.

notes: a mill is connected to the
installation. The governorate expects the
construction and installation of a new wheel

photos: Figs. 365-369

61

name: zūr Abū Zayd
location: Ḥamā towards ‘Ashārīna,
Qamhāna

typology: installation: type A1
tower: type A
aqueduct: type A

technique: limestone and mortar;
reconstructions in reinforced concrete

findings: tower, part of the wheel. A new
aqueduct channel is rebuilt in concrete.
There are parts of the last wheel which had
12 spokes, 80 compartments and a diameter
of 12 metres.

notes: The aqueduct channel is employed to
carry the river water which is raised by
electrical pumps.

photos: Figs. 370-373
name: al-Ḥiṣa 1

location: Ḥamā towards ʿAshārina, Madinat Tibat al-Imam
typology: installation: type A2
tower: type A
aqueduct: type E
technique: limestone and mortar; reconstructions in reinforced concrete
findings: It is entirely built in reinforced concrete.
note: It shares a dam with al-Ḥiṣa 2. It is one of the modern installation built in the 1940s.
photos: Figs. 374, 378

name: al-Ḥiṣa 2

location: Ḥamā towards ʿAshārina, Madinat Tibat al-Imam
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: remains of the triangle and the aqueduct. The tower is rebuilt in stone and the dam is rebuilt in reinforced concrete.
note: It shares a dam with al-Ḥiṣa 1. In 1308/1891 it was mentioned in the waqfiya of Murad Agha (Kamel 1974, 118).
photos: Figs. 375-378

name: al-Mahruqa

location: Ḥamā towards ʿAshārina, Madinat Tibat al Imam
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: remains of tower, triangle and aqueduct
notes: a mill is connected to the installation.
photos: Fig. 379
65
name: al-Ḥamānī
location: Ḥamā towards ‘Ashārina, opposite Shīzar, Shīzar
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: triangle, tower and aqueduct built in stone.
note: it shares a dam with the Shīzar installation. Modern hydraulic pumps are installed nearby.
photos: Figs. 380-382

66
name: al-Shīzar
location: Ḥamā towards ‘Ashārina opposite al-Ḥamānī, Shīzar
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: there are no remains of the original installation. The existing triangle and tower are recent reconstructions built in stone. The wheel is in use. It has 20 spokes, 80 compartments and 20 additional compartments
notes: It shares a dam with al-Ḥamānī The wheel was built and installed in 2003 Modern hydraulic pumps are installed nearby.
photos: Figs. 381-383
67
name: zur al-Thalātha
location: Ḥamā towards ‘Ashārina, Shīzar
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar
findings: remains of three arches of the aqueduct
notes: In this area there is no water any more; the river is completely dry.
photos: Fig. 384

68
name: Zūr al-Traymisa
location: Ḥamā towards ‘Ashārina, Traymisa
typology: installation: type A1
tower: type A
aqueduct: type A
technique: limestone and mortar
findings: remains of two arches of the aqueduct. One hundred metres from the original remains there is part of a new aqueduct rebuilt in reinforced concrete (pillars and aqueduct channel)
note: Nearby there are remains of a mill and of the modern aqueduct which was built in reinforced concrete in 1954 and was in use until 1960.
photos: Fig. 385

69
name: Shahābiyyat Tall ‘Ayyūn
location: Ḥamā towards ‘Ashārina, Shīzar
typology: installation: type C2
tower: type A
aqueduct: type A
technique: limestone and mortar; reconstructions in reinforced concrete
findings: Of the original structure only remains of the triangles are preserved. They are made of stone and mortar. The whole structure is rebuilt in reinforced concrete, except one tower and the triangles which are made of stone.
note: In this area there is no water any more; the river is completely dry.
photos: Figs. 386-388
name: al-‘Ashārīna
location: Hama towards ‘Ashārina, ‘Ashārina

typology:  installation: type A2
tower: type B
aqueduct: type A

technique: limestone and mortar

findings: of the original ancient installation there are remains of the foundation on which the actual structure was built in the early 20th century. It includes the two triangles, the two towers and the aqueduct. The whole is built in stone.

note: In this area there is no water any more; the river is completely dry. A mill is connected to the installation. The governorate expects the installation of a new wheel in 2005/2006. On the aqueduct there is an inscription with the date of restoration (1920).

photos: Figs. 389-390
3. SUMMARIZING TABLES

Table A) Installations with existing wheels or where new wheels are expected to be installed

<table>
<thead>
<tr>
<th>Name of the installation</th>
<th>location</th>
<th>Number of wheels</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zūr al-Ashiq</td>
<td>Rastan toward Hāmā</td>
<td>wheel</td>
<td>wheel in ruins</td>
</tr>
<tr>
<td>al-Kharīsa</td>
<td>Rastan towards Hāmā</td>
<td></td>
<td>New wheel expected</td>
</tr>
<tr>
<td>al-Dawwār</td>
<td>Hāmā</td>
<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-Bishriyyat</td>
<td>Hāmā</td>
<td>4 wheels</td>
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</tr>
<tr>
<td>al-Jisriyya</td>
<td>Hāmā</td>
<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-Ma’āmūriyya</td>
<td>Hāmā</td>
<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-Mu‘ayyadiyya</td>
<td>Hāmā</td>
<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-‘Uthmāniyyatān</td>
<td>Hāmā</td>
<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-Gharbiyya</td>
<td>Hāmā</td>
<td>1 wheel + 2 wheels</td>
<td></td>
</tr>
<tr>
<td>al-Ṣahyūniyya al-Rawaniyya</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>al-Kilāniyya</td>
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<td>1 wheel</td>
<td></td>
</tr>
<tr>
<td>al-Khudūra</td>
<td>Hāmā</td>
<td>1 wheel + 1 wheel</td>
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<td>Hāmā</td>
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<tr>
<td>al-Jawhariyya</td>
<td>Hāmā towards ‘Ashārina</td>
<td>1 wheel</td>
<td></td>
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<tr>
<td>Kazo al Kabira</td>
<td>Hāmā towards ‘Ashārina</td>
<td>new wheel expected</td>
<td></td>
</tr>
<tr>
<td>al-Arza</td>
<td>Hāmā towards ‘Ashārina</td>
<td>1 wheel</td>
<td>wheel in ruins</td>
</tr>
<tr>
<td>al-Bilhusayn</td>
<td>Hāmā towards ‘Ashārina</td>
<td>1 wheel</td>
<td>wheel in ruins</td>
</tr>
<tr>
<td>al-Nāṣirīyya</td>
<td>Hāmā towards ‘Ashārina</td>
<td>new wheel expected</td>
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<tr>
<td>zūr abū Zayd</td>
<td>Hāmā towards ‘Ashārina</td>
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<td>wheel in ruins</td>
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<td>Hāmā towards ‘Ashārina</td>
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<td>new wheel</td>
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<td>new wheel expected</td>
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<td>Name of the installation</td>
<td>Type of installation</td>
<td>Type of tower</td>
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<td>2</td>
<td>zu'ūr al-'Ashīq</td>
<td>A1</td>
<td>A</td>
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<td>3</td>
<td>Ghūr al-Āṣī</td>
<td>A1</td>
<td>A</td>
</tr>
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<td>4</td>
<td>Marīj al-Dur</td>
<td>C2</td>
<td>B</td>
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<td>Qabībat al-Āṣī</td>
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<td>A</td>
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<td>zu'ūr Abū Darda</td>
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<td>A</td>
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<td>al-'Āsila</td>
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<td>al-Jumāqiyya</td>
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<td>al-Taqsīs</td>
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<td>B</td>
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<td>al-Jarnīyya</td>
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<td>C</td>
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<td>A</td>
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<td>C+C</td>
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<td>źūr al-Traymīsa</td>
<td>A1</td>
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<td>Shahābiyyat Tall ʿAyyūn</td>
<td>C2</td>
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<td>70</td>
<td>al-ʿAshārīna</td>
<td>A2</td>
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4. SUMMARIZING DATA

A) Types of installation

- n. 43 installations type A1
- n. 12 installations type A2 (11+1 because al-Bishriyyat includes two types of installation)
- n. 6 installations type B1
- n. 1 installation type B2
- n. 1 installation type B3
- n. 1 installation type C1
- n. 4 installations type C2
- n. 3 installations are no recognizable

B) Types of tower

- n. 65 towers type A
- n. 7 towers type B
- n. 5 towers type C
- n. 1 tower type D
- n. 1 tower type E
- n. 1 tower has completely disappeared

C) Types of aqueduct

- n. 62 aqueducts type A
- n. 2 aqueducts type B
- n. 1 aqueduct type C
- n. 1 aqueduct type D
- n. 4 aqueducts type E
- n. 9 aqueducts have completely disappeared

- 70 locations preserve groups of installations of which 18 have wheels. 69 belong to the Hamah governorate and 1 belongs to the Homs governorate.
- 24 wheels are in existence, of which 20 are in use. 4 wheels more will be installed in 2005/2006 according to the programme of restoration and conservation by the Hamah governorate.
- 22 groups preserve wheels or new wheels are expected to be installed.
CHAPTER EIGHT

CONCLUSION

This study has attempted to clarify and to understand the importance of a significant typology of water-architecture in Syria. By combining historical, architectural and iconographical material, the study has shown that Syrian water-wheels are a particular type of water-architecture, which successfully combine the functional with the aesthetic and display sophisticated forms of construction. They present a variety of shapes and detailed designs, and have practical and environmental importance. An attempt has been made to present evidence for their ancient origin and to understand the development and evolution of their design, the reasons for their significance and uniqueness, and their heavy concentration in Syria.

On the basis of the results of this research, some observations can be offered to underline the major issues that have emerged and the important points that have been touched on throughout the thesis.

It is hoped that this work throws some light on the role that Syrian water-wheels have played over the centuries and has highlighted the need for the further consideration and attention that these types of water-structure deserve.
1. TERMINOLOGY AND TYPOLOGY

Before analysing the structures, it has been necessary to make clear the problem of the terms adopted to indicate the different types of installation and their classification. One of the main difficulties in dealing with the classification has been the variety of types of water-wheels used in the past, and the fact that different terminology has been used, not only by different scholars, but also in different countries.

The terminology that has been adopted employs universal words known across Europe and the Middle East, and has attempted to integrate the different vocabulary used so far which has sometimes made the distinction between the various types unclear.

The three main groups identified, and their attendant sub-classifications, are related to the types of water-wheels moved by three different sources of power, i.e. water, animals and men, which developed to raise water for several uses. The large diffusion that these water-wheels have had over time in a broad geographical sense, until the advent of new oil and electricity-based technologies, is due to their numerous advantages. These advantages include the simple and efficient mechanism of these structures, the easy assembly and maintenance of the wheels, their happy integration into the landscape and the simplicity and economy of their construction. Of the two groups identified in Syria, i.e. water-wheels moved by animals (sāqiyas and norias) and those moved by water (hydraulic norias) the latter, on which this study has mainly focused, have undoubtedly played a fundamental role in Syrian cultural tradition.
It is important to underline the fact that hydraulic norias have revealed significant characteristics not only in their functional aspects, but also in their unique artistic qualities and designs, unlike animal-powered machines which can be evaluated only for their technological and utilitarian aspects. As has been noted, in the construction of the wheels of săqiya and norias, no geometric motifs were followed, while more attention was paid to the construction of the masonry works. This was essentially due to the fact that these structures did not have a real elevation because they were partially inserted into the ground. Thus, no significant distinction in terms of shape of the wheels has been noted in the săqiya and norias in a broad geographical sense.

As has been noted, Syrian hydraulic norias have a more complex structure than in other countries, not only to exploit fully the advantages provided by the topographical characteristics of Syria, but also to create constructions of real architectural merit with specific typological characteristics.

2. ORIGIN

A further general theme is that of the sources analysed in order to understand the probable origin and the development of the typology in a broader geographical context as well as the introduction of water-wheels in Syria.

Up to now, the hypotheses put forward by scholars have differed greatly and have not been supported by enough convincing evidence. In addition they often did not specify which typology of water-wheel they referred to; and because no common terminology was used, the exact type of water-wheel they referred to
was not clear. The sources analysed have included archaeological findings, literary texts and architectural treatises. Treated individually, all these sources have limitations, but by bringing them together, it has been possible to establish a far clearer picture of the development of the water-wheel over time.

The results provided by the sources have clarified with certainty a diffusion of the three identified types in existence since Roman times, and the sāqīya and noria existed in Egypt from at least the 3rd century B.C. The existence of treadwheels can be documented by sources at least two centuries later, again in Egypt. The earliest evidence of hydraulic norias also dates back to the 1st century B.C., but the place is still uncertain.

However, the hypothesis of an earlier existence of animal-powered machines has been put forward. The links between sāqīya and fujjāra lead us to date animal-powered machines back to at least the 6th century B.C. in Syria. As has been noted, the first fujjarāt would have been built in Syria in the 6th century B.C. as a variant of the qanāt, a typology transmitted from Persia to Syria when this region was incorporated as a province within the Persian empire. Because the only possible means of raising the water collected in the underground basin of the fujjāra was an animal-powered machine, it is likely that the first sāqīya and noria were in use in Syria at this time.

On the basis of the evidence available, a theory of the origin of the Syrian hydraulic noria has been put forward, namely that it first appeared in Roman

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400 Weulersse 1946, 284.
401 The issue is related to the difference between qanāt and fujjāra and their introduction in Syria, which, as has been seen, is significant for understanding the origin of animal-powered machines.
times between 60/50 B.C. (the date of the first descriptions of hydraulic norias by Vitruvius and Lucretius) and the early 3rd century A.D., when Heliogabalus first identified the Orontes valley as the place where he had seen a hydraulic noria and when the Roman sanctuary was built in Ḥamā. The earliest hydraulic norias would have been constructed following the technical and detailed descriptions by Vitruvius in the 1st century B.C.; his treatise is certainly the earliest work referring to hydraulic norias. The original design of the wheel probably differed from those in existence today.

The hydraulic noria represented in the 5th-century mosaic from Apamea, which has traditionally been considered the only evidence for a Roman origin of these devices on the Orontes, shows a hydraulic noria whose shape could have changed after the advent of Islam. As has been noted, it has a triangle like the installations today, but the design of the wheel is not the same. The wheel has radial spokes which start from the centre.

As several sources have demonstrated, precise radially is a characteristic of Roman water-wheels. With the advent of Islamic technology, the design of the wheel may have changed, while aqueducts and towers would have preserved the original shape. Through the analysis of architectural Islamic treatises dealing with water-wheels, an impressive similarity has been noted between the design and the geometric construction of the Orontes wheels with 24 spokes and the drawing of a wheel which turns because of the weight of the mercury filling the pipe-spokes, a drawing contained in an anonymous Arab military manuscript.

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402 We have seen this shape shown in Vitruvius’s drawings from the 1st century B.C., in the 2nd century A.D. hydraulic norias found at Venafro, in Italy, and at Barbegal, in France, and also in the water-wheel represented in the 3rd century Maius cemetery in Rome.
probably written between the 9th and the 12th centuries. It is possible that the Arab architect who first built water-wheels adopting a new design may have been influenced by the studies in this anonymous manuscript, which shows a wheel whose design is ideal for the big wheels on the Orontes. Indeed, this design allows the best distribution of the forces transmitted by the great power of the river. It is most likely that the Islamic design of the wheel has not changed up to now, as it corresponds to that of the wheels in existence.

3. REGIONAL VARIATIONS

A further important theme which has emerged in this study is the variety of shapes of hydraulic noria in a broader geographical sense. As the sources have also demonstrated, the use of the water-wheel has been widespread and fundamental over the centuries and its mechanism has been able to be easily combined with different designs.

Hydraulic norias have traditionally been considered a utilitarian means of raising water from the river for domestic and public purposes, and their aesthetic aspects have been neglected. The architectural treatises analysed, which have dealt with water-wheel over the centuries, have shown that the mechanism of water-wheels can be combined successfully with many shapes, often characterized by decorative motifs. By comparing the visual material available it has been possible to identify a differentiation in wheel designs which has characterized different regional contexts. Various different geometric motifs are the results of
precise geometric constructions.

It has been shown that the design of the wheels can be characterized by "radial" and "polygonal" shapes, or by a combination of these. This identification has underlined the uniqueness of the "polycentric" radiality of the Orontes wheels, obtained by combining the best hydraulic and mechanical efficiency with a detailed geometric construction, in order to deal with the strong current of the river.

It has also been noted that the type of wheel design is linked to the strength of the current in other rivers. Polygonal shapes, with a reduced number of radial spokes and a predominance of oblique secondary beams, of the type used on the Guadalquivir river in Spain, on the Nabão river in Portugal and in the Maghrib, deal with weaker river currents, unlike wheels with a radial shape which are able to support a greater river power, like the Turkish examples or the East Asian water-wheels.

The Syrian types are the strongest. The secondary spokes, starting from 4 centres equidistant from the circumference and from each other, create a natural strengthening of the main beams, making the structure more resistant to the forces of inertia and gravity, to hydraulic and transversal thrusts, and preventing major warping.

A further significant aspect which has emerged is that Syrian hydraulic norias distinguish themselves from the installations in other countries not only because of the unique design of the wheel and their carefully elaborated aqueducts, but also thanks to the presence of secondary works, such as dams and passages of water that guarantee control of the strong river current. Thus, as will
be underlined later, they were probably added to the fundamental parts of the structure, i.e. the wheel, tower and aqueduct when, starting from the 9th century, a new wheel design was adopted in order to exploit better the power of the Orontes current and thereby to obtain maximum efficiency.

4. SYRIAN WATER-WHEEL DESIGN

As already noted, hydraulic norias, säqiyas and norias have been identified in Syria. An important aspect that has emerged by analysing these structures is that Syrian hydraulic norias are real “architectural works” where the three fundamental components, i.e. wheel, tower and aqueduct, are all characterised by complex design patterns and architectural details.

Up to now the value and importance of Syrian hydraulic norias has been related far more to their functional aspects and the advantages provided to the immediately surrounding lands. The analysis of the structures in western Syria, on which the study has focused, has demonstrated that Syrian hydraulic norias have played a particularly significant role in combining design, efficiency and respect for the environment, and that they were also an authentic expression of an architecture with specific and defined artistic connotations.

The hydraulic norias of the Orontes have been traditionally considered as being based on only a single pattern; this is due to a lack of previous detailed surveys of the installations and related architectural material. Through a direct analysis of all the structures along the river, drawings, architectural findings and
architectural comparative material, this study has made it possible to identify a variety of types of hydraulic norias and to understand the probable original design of these structures and how they have changed their original shape.

Thus, an interesting point that has emerged is the connection of the designs of towers and aqueducts with Roman architecture, not only as far as the patterns are concerned, but also in terms of structural solutions. These characteristics have been particularly evident in the case studies analysed in detail, which can be considered representative of those numerous installations of which only a few remains have survived.

For instance, the example of al-Muḥammadiyya has shown how the original Roman shape would have been based on a rhythmic alternation of a double row of arcades and how, when changing the shape into a single row of high arcades in the 14th century, it was necessary to stabilize the piers with buttresses.

Through the example of al-Mardīsha it has been shown how the aqueduct design is based on a modular sequence of square motifs which is the pattern for the rhythmic disposition of the two rows of arcades. This shows the adoption of one of the commonest varieties of intercolumniations described by Vitruvius. It has also been shown how this design brings to mind one of the most popular Roman post-Augustan aqueducts.

Analysis of al-Qarnāsiyya shows another aqueduct design linked to Roman constructions. Because the state of the remains does not permit an understanding of the original shape with certainty, virtual reconstructions of the probable original design have been done. They have made it possible to determine
the ideal solution which could have been adopted and which evokes the typology
of cross-braced arched pier aqueducts like that at Merida in Spain.

The lack of remains of masonry works and related architectural evidence
of the Aleppo hydraulic norias on the Quwayq, has blocked an understanding of
the aqueduct and tower designs of these installations, nor is it possible to make
general observation on these features.

The question whether the hydraulic norias on the Orontes originally had
pots instead of compartments still remains unproven. As has been noted, the
mosaic from Apamea, which is the earliest iconographical source for the hydraulic
norias on the Orontes, does not provide clear evidence of the means to raise water.
Burckhardt’s and Ewbank’s descriptions of the Orontes also do not provide
convincing information for asserting the presence of pots on the rim of the wheel.
In addition, the fact that the wheels with pots were characteristic of small
hydraulic norias, like those on the Euphrates and Khabûr, make the use of pots in
the Orontes wheels less convincing.403

5. DATING

Hydraulic noria

As already indicated, dating has been made difficult because of the lack of well-
preserved structures from the early period and their frequent alteration and

403 It should be remembered that the Orontes wheels have a very large size. As we have seen, they
can reach, in fact, a diameter of more than 20 metres.
restoration. On the basis of the sources analysed, the study has clarified the existence of hydraulic norias in Syria from at least the 3rd century A.D. on the Orontes river, as a technology transmitted by the Romans.

The analysis of the findings and shapes of the hydraulic norias has also shown connections between some ancient installations and Roman imperial architecture. Although we cannot assert when the structures that have been found were originally built, comparative architectural material, and the fact that some remains could have survived over centuries, have contributed evidence for their possible early origin. This has been supported by many factors, such as the similarity of some aqueducts with Roman examples and of some towers with the triumphal arches, or the structural solutions, similar to those adopted by the Romans, employed to deal with the structural stability of the aqueducts. The issues discussed on the design, for instance, of al-Mardisha, al-Qarnāšiyā and al-Muḥammadiyya, have underlined the possibility of a pre-Islamic source for the shape adopted in these structures.

A significant point that has emerged is that secondary masonry works, i.e. dams and passages for water, would originally have been constructed when the shape of the wheel changed after the advent of Islam, between the 9th and the 12th centuries. As has been noted, because secondary works increase the power of the river through the main channel to the wheel, it was necessary to make the wheel considerably stronger. This meant that new wheels, dams and barrages, would

404 As has been seen, some remains could have survived over centuries because of their location and their durability. The structures were built in the lee of hills and, consequently, naturally protected from atmospheric agents, and the masonry works were water-proofed and strengthened due to the calcium contained in great quantity in the river water, which tends to deposit a thin layer on the limestone walls.
have been built together, after the 9th century, to exploit better the power of the river.

_Saqiya and noria_

As far as animal-powered machines are concerned (sāqiya and noria), it has been noted that these structures easily disappeared, being mainly made of wood, and because they were mainly housed underground and consequently were difficult to find. Although the earliest evidence of a sāqiya in Syria traditionally dates back to the 13th century, it is interesting to note that the comparable architectural material analysed here supports the theory that this typology could have existed in Syria already during Roman times, from the 3rd century A.D. Moreover, it has been shown that animal-powered machines did not develop in isolation, and links with the _fujjarāt_ have demonstrated the importance of their role over time and the possibility that the sāqiya and noria were introduced in Syria earlier, in the 6th century B.C..

While Syrian hydraulic norias, as this study has shown, are the most visually impressive devices, sāqiyas and norias have been considered for their functional and utilitarian aspects, rather than for architectural characteristics. However, the significant example in Damascus shows that Syrian animal-powered machines were once detailed and complex structures and the result of a sophisticated technology.
6. DESIGN AND LANDSCAPE

On the basis of the evidence available, the difference in topographical characteristics between the Orontes and Quwayq rivers can certainly be regarded as an important element in understanding the designs of the wheels. The choice of the design of the wheel is linked to the degree of river power.

It has been noted that the Roman shape, which originally could have characterized both the Orontes and Quwayq wheels, has been preserved only for the hydraulic norias which existed at Aleppo on the Quwayq. The Orontes wheel shape may have changed with the advent of Islam, as a consequence of new studies of raising-water contrivances, in order to deal with the stronger current of the river and to guarantee the most efficient exploitation of hydraulic power. The new typology would have been created by combining the necessity of an improvement in efficiency with a geometric and decorative construction based on the intersections of star-shaped motifs. In contrast, owing to the weaker current of the Quwayq, the Aleppo water-wheels would probably have preserved the original Roman shape.

A further important aspect that has emerged from this study is the integration between architecture and nature. The hydraulic norias of the Orontes display a typology integrated with the characteristics of nature and links between them and the surrounding lands have been identified.

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405 On the basis of the sources, the earliest Islamic studies on water-wheels are probably those by the Banu Mūsā brothers in the 9th century. However, as has been shown, the passage of the shape of the Orontes wheels from “Roman” to “Islamic” could date from a period between the 9th and the 12th century.
406 In fact a wheel with a perfectly radial shape, like the Aleppo one, well supports a water pressure which is not particularly strong, while the greater current of the Orontes necessitated a different design.
The Orontes valley has been the ideal place for the development and diffusion of hydraulic norias because of the particular characteristics of the river and of the surrounding hills. In addition, a close integration of these structures into nature has been shown by the use of the materials employed to make the structures, which are easily available, like mulberry and local limestone, and by the fact that the chemical characteristics of the river water improve the durability of the masonry. It is interesting to note that the durability of the foundations has allowed an understanding of the type of the structures.

A further link between hydraulic norias and landscape is forged by the fact that the light structure of the wheels makes them appear part of the natural landscape. Furthermore, as has been noted, the uniqueness of the structure of the wheel design is not only the result of an architectural process, but is also due to the necessity to exploit fully the power of the river.

The analysis of the Orontes structures has revealed that the integration between architecture and landscape is reflected in unique solutions in the layout of some hydraulic noria, as we have seen in al-Masāliq and al-Ḥāmid.

7. RE-EVALUATING SYRIAN WATER-WHEELS

As we have seen, as a consequence of technological progress and of the increasing necessity of water for public and domestic purposes, the water-wheels have stopped working and most of them have been abandoned and have quickly deteriorated considerably. The only project dealing with Syrian water-wheels is the ongoing programme of hydraulic noria restoration set out by the government
of Ḥamā, which, however, aims to preserve only those installations which are easy to reach and are in a better state of preservation. In addition, because of the scarcity of material aimed at increasing the awareness and knowledge of Syrian water-wheels, their cultural and historical value remains underrated.

In the light of the close study of all Syrian water-wheels and their important role played over time, a possible re-evaluation has been considered. By evaluating the feasibility of renovating hydraulic norias as a sustainable system, as well as an expression of historical and cultural heritage, it has been noted that a re-employment of the hydraulic norias for their original purpose would present considerable difficulties, despite the advantages that it could provide. An eventual rehabilitation of hydraulic norias would be very difficult not only because the big hydraulic works carried out in the Orontes valley have reduced the level of the river, but also because, owing to the deteriorating state of most installations, a restoration aimed at re-activating them would mean reconstructing, in many cases, entire aqueducts or demolishing recent constructions abutting on the remains of aqueducts.

Apart from the difficulties in rehabilitating hydraulic norias for their original purposes, this policy could also diminish the cultural value of the structures, as they might be seen as primarily utilitarian.

The preliminary proposal which has been put forward here has aimed to re-evaluate Syrian water-wheels in terms of historical heritage and ancient tradition. It has also attempted to underline the fact that these water structures are powerful in their multiple connotations and sustain a particularly significant position in the history and culture of Syria. They should be placed firmly within
the repertory of historical water typologies as well as within Syria’s architectural heritage.
ILLUSTRATED GLOSSARY

**Additional paddle** (*bab*)
Paddle fixed to every spoke during period of plentiful flow. They are submerged when the level of water is high.

**Aqueduct**
Structure to transport the water from the wheel to the fields through a channel on the top. In a hydraulic noria it is possible to consider as “aqueduct” the part of the structure perpendicular to the wheel (composed of a sequence of arches), and “tower” the part parallel to the wheel (see “tower”).

**Aqueduct channel** (*hajiariyya*)
Channel into which water is poured from the upper part of the wheel in a hydraulic noria.

**Basin** (*qas'a*)
Basin made of wood to receive water poured by the pots or compartments of a säqiya or noria

**Bearing** (*kift*)
Wooden support of the horizontal axle of a hydraulic noria. It is placed on the top of the triangle and on the sill of the tower aperture.

**Boundary wall** (*hetat al-madar*)
Low wall made of earth which surrounds the circular track (*madār*) of a säqiya or noria to prevent animals who move the machine from going off the track.

**Bucket-wheel**
A water-wheel using enclosed buckets or clay pots around the rim, against which, or into, the water flows.
Circular track (*madār*)
Elevated circular track on which animals move to drive a sāqiya or noria. It is surrounded by a low wall made of earth ("boundary wall").

Compartment spout (*mad*)
Aperture of wheel compartments through which water is poured into the aqueduct channel.

Compartmented wheel
Water-wheel with compartments on the rim (see "compartments")

Compartments (*akwāb*)
Box containers placed on the periphery of the water-wheel which fill with water at the bottom and transport the water to the top of the wheel during the circular motion.

Dam (*jisr*)
Construction made of masonry which bars the river where a hydraulic noria is located in order to guarantee optimum efficiency of the wheel. It can be placed perpendicular to the river banks or diagonally across the river in order to direct the current towards the main channel. Along the dam there are supplementary channels with barrages to regulate the water level. There can also be smaller gated sluices in the dam itself which perform a similar function.

Drop arch
Arch which derives from the intersection of two arches with different centres which are on the same springing-line (horizontal plane from which an arch begins to rise). The span (distance between the two supports of an arch) is longer than the radius.

External and internal face of the compartments (*qabbūn*)
Upper and lower face of wheel compartments.
External rim (*dāʿira al-khārijiyya*)
External wooden rim to which the radial paddles are connected in the wheel of a hydraulic noria. Pots or compartments are fixed to the rim in order to raise water during the rotation of the wheel.

**Fujjāra**
Underground channel, similar to the *qanāt*, which carried water from a natural source to an underground basin (*sahrij*). From there water was raised by a *sāqiya* or noria.

**Fork bar** (*sarīr*)
Fork-shaped bar on which a person is seated to drive the animal to move the *sāqiya* or noria. It is linked to the yoke (*karāb*) by a rope.

**Four-centred arch**
Arch derived from the intersection of two pairs of arches which have the springing lines at two different levels. One pair of arches have their centres below the springing-line; the other pair of arches have the centres on the springing-line.

**Horizontal axle** (*sahm*)
Horizontal axle which links the potgarland wheel (*mahalla*) with the vertical cog-wheel (*janb*) in a *sāqiya* or noria.

**Horizontal axle** (*qalb*)
Horizontal wooden axle on which the wheel of a hydraulic noria turns. It sits on the bearing on the sill of the tower window.

**Horizontal cog-wheel** (*tars*)
Horizontal wheel with cogs in a *sāqiya* or *noria*. It is moved by the rotation of the vertical axle. By turning, it moves the vertical cog-wheel (*janb*) which is connected to the potgarland wheel (*mahalla*). It corresponds to the *tabqq*, according to the terminology adopted by al-Jazari.
**Horizontal water-wheel**
A wheel which revolves in a horizontal plane but whose main power shaft is vertical.

**Hydraulic noria** (*nāʿūra*)
System for raising water from a river through a vertical water-wheel using hydraulic power. The wheel deposits the water into the aqueduct, which then supplies homes, public buildings and farms.

**Internal rim** (*dāʿira al-dākhiliyya*)
Wooden rim passing through the pairs of spokes in the wheel of a hydraulic noria.

**Lateral face of the compartments** (*jabaq*)
Ring strip placed on the periphery of the wheel, in a hydraulic noria, which, in pairs, forms the lateral sides of the compartments.

**Loggia for repair** (*khāristān*)
Aperture or niche in the tower of a hydraulic noria to allow access for maintenance.

**Main channel** (*tamm; bib*)
Channel between the tower and the triangle of a hydraulic noria to house the wheel.

**Main paddle** (*jāmiʿa*)
Wooden plate placed radially on the periphery of the wheel in a hydraulic noria. Water pressure on the paddles causes the rotation of the wheel.

**Main spokes** (*ʿidān*)
4 pairs of parallel beams perpendicular to each other on each side of the wheel in a hydraulic noria. They are the main structure of the wheel and are connected to the rims. They are pivoted around a central axle supported at each end by stone walls.
Nave of the wheel (‘ataba)
Short spokes reinforcing the main spokes of the wheel at the centre in a hydraulic noria

Noria
System for raising water from a stream or underground through one or more wheels moved by an animal. It is similar to the sāqiya, but the two vertical wheels are inserted in the same cavity, and are connected to each other by a short horizontal axle.

Opus structile
Roman wall constructed of rough undressed stones placed in a concrete mix of lime, pozzolan, sand and water, also known as opus caementicium, opus caementum or structura caementicia.

Overshot water-wheel
A water-wheel powered by a head of water striking the wheel just behind its vertical centre or just forward of its vertical centre at its highest point of rotation, thus causing the water wheel to revolve in the same direction as the flow of water in the sluice box or sluice way.

Pot-chain (Shalh)
Chain with pots in a sāqiya or noria. It consists of two parallel cords on which pots are tied. The chain turns around the potgarland wheel (mahalla).

Potgarland wheel (mahalla)
Drum-wheel of a sāqiya or noria on which the chain with pots turns. It consists of two parallel pairs of bars perpendicular to each other. There is a gap, between the pairs of bars where the horizontal axle passes through to connect this wheel to that with cogs. Small transversal bars are inserted in the ends of this structure in order to support the pot-chain.
Qanāt
Gently sloping underground tunnel with airshafts at regular intervals. The tunnel extracts groundwater and directs it to surface canals which provide water to agricultural fields or oases.

Radial plate (rādin)
Short wooden plate placed in radial sequence on the periphery of the rim of the wheel of a compartmented hydraulic noria. It forms the vertical face of the compartments.

Rim (dā'ira)
See “external rim” and “internal rim”.

Sāqiya
System for raising water from a stream or underground through one or more wheels moved by an animal. It differs from the noria because the two vertical wheels are connected to each other by a long axle. The simplest saqiyas have only one vertical wheel.

Secondary spokes (wishāh)
Radial beams which stabilise the structure of the wheel of a hydraulic noria. They are 24 (12 per side) or 32 (16 per side).

Stepped corbel
Corbel with two steps on the lower side which characterise the top corners of the towers of Syrian hydraulic norias

Stone pillars (zarānīq)
Two pillars, placed opposite each other, on the edge of the track. They support the load-bearing axle (dahr) of a sāqiya or noria, which lies on the vertical axle of the horizontal cog-wheel, to make the whole structure stable.
Tower (burj)
Fronton of a hydraulic noria which is characterized by a central arched window for supporting the axle of the wheel and by two corbels on the upper corners.

Transversal bar (bisha)
Small bars made of wood, which are inserted into the main bars of the potgarland wheel in order to support the chain of pots in a sæqiya or noria.

Transversal beam (dahr)
Load-bearing axle of a sæqiya or noria, with a thickness of 30 centimetres, which lies on 2 pillars and rests on the vertical axle of the horizontal cog-wheel, to make the whole structure stable.

Treadwheel
Vertical water-wheel moved by man power to raise water through compartments placed on the rim.

Triangle (muthallatha)
Triangular wall to support one of the ends of the horizontal axle of the wheel in a hydraulic noria. On both sides it has steps to allow access to the nave of the wheel for maintenance.

Tympanum
Vertical water-wheel in the shape of a circular drum with cavity segments on the periphery to raise water during the rotation. It is the Latin name used by Vitruvius to indicate a treadwheel with compartments.

Undershot water-wheel
A water-wheel powered by a head of water striking the wheel at a point near the bottom, causing the wheel to revolve.
**Vertical axle (ʿarūs)**
Vertical axle, made of wood, which supports the horizontal wheel with cogs (tars) in a sāqiya or noria.

**Vertical cog-wheel (janb)**
Vertical wheel with cogs moved by contact with the horizontal wheel in a sāqiya or noria. Through a horizontal axle it transmits the movement to a wheel with pots which raises water from a stream or from underground.

**Window (nāfidha)**
Arched window in the aqueduct tower, which supports one of the ends of the horizontal axle of the wheel in a hydraulic noria.

**Wooden bar (karab)**
Wooden bar or long yoke, in a sāqiya or noria, which connects the animal with the vertical axle of the horizontal cog-wheel, enabling the movement of the machine.
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