Irrigation and Hydraulic Technology in Islamic Spain: Methodological Considerations

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While a discussion of the history of irrigation systems may seem at first glance tangential to the concerns of a meeting on the history of science and technology , I will argue here that irrigation agriculture taken as a whole has obvious technological ramifications . Obviously the development and diffusion of the physical appurtenances of irrigation systems , such as dams , canals, aqueducts , *Qanats* , siphons and so forth fall within the domain of technological history as do lifting devices from the Archimedes screw and the shaduf to the current - and animal - driven norias . Noria technology is related to that of milling , which also falls within our discussion . But I would also add that the legal and institutional arrangements by which water is distributed for use in irrigation canals and for mills is no less a technology , because such arrangements have a direct impact upon the human use of a natural resource, water , and any kind of mediation between society and natural resources is , by definition , a technology . Emphasis on machinery and physical objects may cause us to forget that the history of technology is the history of technical ideas, whether those ideas are put into effect through physical objects and processes or through social and institutional mechanisms . (Thus , different modes of allocating water affect the efficiency with which water is used for agriculture.) In this broader sense , the history of technology is very close conceptually to the history of science and to the history of ideas generally .

1 . Hydraulic Societies

Irrigation and hydraulic technology may be approached at a number of levels , from the general to the particular . At it's most general , there is the old , but still pertinent (particularly in Middle Eastern history) debate over the role of irrigation in the origin of civilizations and the nature of social and political organization in so-called *hydraulic societies.* Social theorists of the past century (Hegel first , and then Marx) and anthropologists of the present (Gordon Childe and Julian Steward were the most important theorists) noted the relationship between the bureaucratic requirements of water management (both irrigation and flood control) in arid regions and the origins of the high civilizations of antiquity (Assyria , Babylonia , Egypt , the valleys of the yellow and Indus rivers and , in the new world , Mexico and Peru) . The political and social ramifications of such hydraulic civilizations were then theorized by Karl Wittfogel , a non - orthodox Marxist , in a famous book titled *oriental*

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Despotism (1957) . His general conclusion was that through a process of environmental stimulus and institutional response , hydraulic societies developed a distinctive kind of despotic regime (a more finely defined version of Marx's model of *Asiatic society* characterized by *agro- managerial bureaucracies* , as well as by religions with complex priestly classes , the development of science , in particular astronomy and mathematics which were needed to analyze the hydrological cycle, and other characteristic social , institutional and cultural forms .

To establish a context for the present discussion , I wish to give a brief synopsis of what Wittfogel had to say , not about antiquity , but rather about Islamic civilization in historical times . Following Adam Mez , Wittfogel concentrated on the ʿAbbasid empire , noting :

> The number and variety of the great hydraulic areas that for shorter or longer periods lay within the jurisdiction of the Baghdad caliphate : Egypt , South Arabia , Babylonia , Persia (northeast and south Transoxania and Afghanistan) . All these areas posed *great irrigation problems* , and the Arab sources note both the technological means and the numerous personnel required to solve them [1].

The section of Mez that Wittfogel cites here is one that deals mainly with the organization of irrigation in ʿAbbasid Persia , in particular the *dīwān al - mā'* of Marw [2], a large bureaucratic office with ten thousand employees overseeing a huge system of dams and canals.[3]

Wittfogel also discussed Islamic Spain , in a section devoted to *agricultural civilizations crossing the institutional divide,* By this he meant various historical cases of societies that pass from one stage of human social evolution to another as when non- hydraulic pastoral societies become hydraulic societies . Spain provided Wittfogel with an excellent historical laboratory in which to test his hypothesis[4] .When Spain of the pastoral, sheep - herding Visigoths was conquered by the Muslims it became,in Wittfogel's view .

> " a genuine hydraulic society , ruled despotically by appointed officials and taxed by agromanagerial methods of acquisition . The Moorish army , which soon changed from a tribal to a *mercenary* body , was as definitely the tool of the state as were its counterparts in the Umayyad and Abbassid caliphates .

1 . Wittfogel , *oriental Despotism* (New Haven , 1957) , p . 167.

2 . Mez , *El renacimiento del Islam* (Madrid , 1936) , pp . 533 - 540 , especially pp. 534 - 535 .

3 . See also Claude Cahen , "Le service de 1' irrigation en Iraq au début du XIe siècle , " *Bulletin d'Etudes Orientales* (Damascus) , 13 (1949 - 50) , 117 - 143. For similar institutional arrangements , Ann K . S. Lambton , " The Regulation of the waters of the zayande Rud , " *Bulletin of the School of oriental studies* , 9 (19xx) , 663 - 674 .

4 . *Oriental Despotism* , pp . 214 - 219 .

> Aprotoscientific system of irrigation and gardening was supplemented by an extraordinary advance in the typically hydraulic sciences of astronomy and mathematics. Contemporary feudal Europe could boast of no comparable development[5].

Wittfogel's sources were quite old but worthy for the times . For general information he depended in great measure on Dozy , although he had more appropriate sources for the finer points : on appointed officials and mercenary army , Andalusi chronicles reproduced in Spanish translation by Sanchez Albornoz , as well as the discussion of Lévi - provençal ; on Andalusi agronomy , astronomy and mathematics , Aldo Mieli's *La science arabe* (1938). Nor has this picture substantially changed : if anything , Crone's view of tribal militias replaced rather early , and precociously in al - Andalus with respect to the Islamic East , by a non tribally - based military organization , lend credence to Wittfogel's view of state organization typical of *oriental despotism* [6]. Historians of science , of course , have further develobed the extraordinary history of the exact sciences in al - Andalus , especially astronomy , which is the hydraulic science par excellence in Wittfogel's view because of the need for calendrical calculations that bureaucrats as well as farmers require in order to maximize their scarce water resources . The Andalusi agronomical school created a highly distinctive body of literature , some of which (notably the treatise of ibn al - ʿAwwām) was oriented towards irrigation agriculture .

Nevertheless , Wittfogel's view of Andalusi society is deformed by the nature of the sources on which it rests , namely palatine chronicles and the products of high scientific culture . In fact there is no evidence of any wide - scale hydraulic works directed by an agromanagerial bureaucracy . There was nothing like an Iraqi *dīwān al - mā'* ñ Indeed the heartland of the caliphate, the *campiña de Cordoba* , was a wheat - growing area , unirrigated . The results of archeological studies of irrigated areas in eastern and southern Spain are consistent with Samir Amin's *tributary model* (which is in a sense agro - managerial in Wittfogel's sense - but then so is almost any centralized tax system) , but the irrigation systems themselves appear to have been highly localized and administered either by tribes , by autonomous communities of irrigators not necessarily tribal , or by municipal administrations , with no regional , much less imperial linkages among them [7]. The only exception to this general picture are the mysterious *ṣagāliba* , Muẓaffar and Mubārak , who ascended from the office of *wakālat al - ṣāgiya* of Valencia to become the

5 . *Ibid* . p . 215 .

6 . Patricia Crone , *Slaves on Horses : The Evolution of the Islamic polity* (Cambridge , 1980) , pp . 75 , 255 note 577 .

7 . This view of irrigation systems serving communitarian interests (even ahead of economic ones) is promoted by Guichard , Barcelo .

first kings of that Taifa state . But we have no notion whatever of what that jurisdiction entailed , although I will hazard a guess below [8].

When the christians conquered al - Andalus , according to Wittfogel , the institutional divide was crossed again , returning the country to the modes of governance typical of pastoral social organization . Again , some of the gross features of post - reconquest Spanish polity and economy fit wittfogel's preconceptions , for example the predominance of the Mesta or sheepherders guild , a symbol of the *replacement of labor - intensive irrigation farming by labor - extensive cattle breeding*[9] .

Here Wittfogel's sources , practically limited to Julius Klein's study of the Mesta[10] and the outdated nineteenth - century accounts of Laborde and Prescott, are not the best . We now know , for example , that irrigated areas such as the Campo de Cartagena were in fact converted to dry - farming and herding and canals actually filled in . But such evidence is in fact atypical .The Christians began their occupation of al-Andalus by compiling huge land registers , the *Repartimientos* a typical agro - managerial instrument[11]; and even though the fragmentation of jurisdictions so characteristic of feudal governance made coordination in hydraulic matters extremely difficult , the royal authority in the kingdom of Valencia was able to mount in the Acequia real del Jucar an irrigation system far more extensive than any canal system surviving from Islamic times . Therefore , it is possible to make a case for crossing the institutional divide but with Wittfogel's terms reversed , whereby a decentralized society with a tradition of fairly independent local rural economic units was replaced by a feudal society , but one with strong tendencies towards centralization of power in the monarchy which , in the crown of Aragon in particular , was stimulated by the revival of Roman law .

Recently Wittfogel's view has reoccurred in a polemic over the social organization of rural al - Andalus , in this case , the Valencian region , or sharq al- Andalus generally . The anthropologist Jack Goody , applying a Wittfogel - style model to Islamic Spain assumes the servile condition of peasantry in irrigated areas , a construction that Pierre Guichard associates with Braudel's dogmatic notion that *In Spain the traveller passing from the secanos to the regadios –from the dry to the irrigated zones- left behind a relatively free peasant to find a peasant slave. Spain had inherited all the great irrigation networks from the Moslems after the Reconquest , taking them over intact along*

8 . See Glick , *Irrigation and Society in Medieval Valencia* , p . 198 .

9 . *Oriental Despotism* , p . 218 .

10 . Julius Klein , *The Mesta : A study in Spanish Economic History , 1273 - 1836* (1920) (Port Washington , Ny , 1964) .

11 . Wittfogel notes the importance of agromanagerial instruments such as the Domesday Book , the great land register of Norman England (*oriental Despotism* , pp . 213 - 214) , without noting the parallelism between it and the *Libros de Repartimiento* .

with the labour force of fellahin who were necessary to keep them in good order [12] . In contrast , Guichard marshals evidence in support of quite a different picture: that of decentralized communal irrigation systems which hardly supports a Wittfogelian interpretation , as I have mentioned above [13].

Wittfogel is important not so much because of his global theories of political organization but rather because , first , he provides a ready - made framework for comparative analysis , even places *within* the Islamic world which includes irrigated regions representing different kinds of climatic situations from arid , to semi - arid , to temperate . Secondly , Wittfogel focuses the problem of irrigation on its social and political requirements and organization . It takes ecological adaptation (which involves necessarily the application of technology) as the starting point both for the elaboration of a typology of social organization and as a means to explain cultural and social change [14]. It legitimizes in a very broad context the historical study of irrigation and hydraulic technology .

2 . *Evidence for the study of irrigation in Islamic spain*

In general , because of the lack of pertinent documentation , irrigation systems of al - Andalus can only be studied either from documents of the christian middle ages , after the conquest , which may record institutional or technical features inherited from the Muslims , or by archeological study of irrigated sites . One set of evidence pertains mainly to the gross economic structure of irrigated areas and of agricultural society in general , but has little to say regarding the social distribution of water although certain hypotheses may be generated . This includes :

1 . Land registers . The *Libros de repartimiento* (Catalan , *repartiment*) , which were registers of grants to christian settlers of properties formerly owned by Muslims , provide a glimpse of the structure of property holdings on the eve of the christian conquest , the division between irrigated and unirrigated lands , and the presence (or absence) of hydraulic devices , in particular mills . In the case of Nasrid Granada , there are inventories of *waqf* properties , called

12 . Fernand Braudel , *The Mediterranean and the Mediterranean World in the Age of Philip II* , 2 vols . (New York , 1972 - 73) , I , 75 .

13 . *Pierre Guichard , Les musulmans de valence et la Reconquête (XIe - XIIIe siècles)* , 2 vols . (Damascus , 1990 - 91) , I , 228 - 232 , commenting on Goody , *Evolution of the Family and Marriage in Europe* .

14. See Jacinta palerm Viqueira , "Sistemas hidraulicos y organizacion social , "Symposium on Hydraulic Systems , Modernization of Agriculture and Migration ,Toluca (Mexico) , 1991 (typescript) . Palerm points out (p. 8) that Wittfogel distinguishes between " unicentric" complex societies , such as those of pre - classical antiquity , where irrigation generated despotic forms of government and pluricentric societies where a variety of political and social structures were generated .

the *Libros de Habices* which provide some information on the distribution of irrigation water [15].

2 . *Archeological inspection of irrigation systems (mainly abandoned ones)* . Archeological research is of obvious importance for the study of the physical properties of hydraulic systems , not only when physical structures such as qanats [16]. canals and mills are concerned , but also in evaluating the role of irrigation in a given community judged by the layout of the system of dams, canals and fields . Based on the methods of " *extensive archeology* " , for example , Barcelo has formulated interesting hypotheses comparing hydraulic layouts in feudal catalunya with those in Islamic Almeria [17].

3 . *place names may sometimes furnish important information regarding the social allocation of water* . Therefore the distribution of water through secondary feeders to settlements with Beni - names in places like Murcia and Gandia have been taken as evidence for a tribal model of water allocation[18].

Archeological and toponymic evidence , however , just like the land registers ,

15 . Certain properties are specified as having so many hours or minutes an irrigation turn , or *dula*, although how such turns were actually organized can not be guessed on the basis of this documentation . See Manuel Espinar Moreno , Thomas F.Glick and Juan Martinez Ruiz, " El término arabe *dawla* " turno de riego " , en una alqueria de las tahas de Berja y Dalias : Ambroz (Almeria) , in *El agua en zonas aridas* , 2 vols . (Almeria ,1989) , I , 123 - 141 .

16 . On *qanats* , see *Les aigües cercades (Els qanat (s) de l'Illa de Mallorca* (palma , 1986) ; and Miquel Barcelo *et al* . , " Arqueologia : La Font Antiga de Crevillent : Ensayo de descripcion arqueologica , " *Areas : Revista de Ciencias Sociales* (Murcia) , 9 (1988) , 217 - 231 .

17 . The mill is located at the heads of waterworks in catalunya , with the irrigation canals coming as a kind of afterthought; while in Almeria, the irrigation of fields comes first , and the mill is the last served . See Miquel Barcelo , " La arqueologia extensiva y el estudio de la creacion del espacio rural " in Barcelo , ed . , *Arqueologia medieval : En las afueras del " medievalismo "* (Barcelona , 1988) pp . 195 - 274 , on pp . 236 - 242 . According to Barcelo , the layout reflects the preeminence of communitarian values in al - Andalus and of feudal values in Catalonia . The hypothesis is interesting , but it occurs to me that such arrangements might well have hydraulic rationales as well : in arid regimes like those of Almeria , characterized by irregular flow and torrential rains , an exposed mill would run the risk of physical damage ; by locating at the end of a canal system , risk of damage is minimized and the controlled flow of water that millers prize is more assured .

18 . The phenomenon was first noted by Pedro Diaz Cassou , *La huerta de Murcia* (Murcia,1887), pp . 157 - 158 . The research was repeated by Julio Caro Baroja , " Regadios y agnaciones , " in *II Jornadas de Cultura Islamica . Teruel 1988* (Madrid , 1990) , pp . 161 - 164 , a curiously dated article which cites no recent work on spanish irrigation systems . On Murcia , André Bazzana and Pierre Guichard , " Irrigation et Société dans l'Espagne orientale au moyen age" , in *L'Homme et l'eau en Méditerranée et au Proche Orient* , J. Metral and p. Sanlaville , eds . (Lyon , 1981) , pp. 115 - 140 , on PP. 128 - 130 .

does not tell us anything about the fine structure of the social organization of water . For this we must have access to documentation about the *operating procedures* whereby water was distributed to irrigators . In the methodology which I follow , it is understood that such procedures embody the social values and economic priorities of the irrigators (and , more broadly , of societies and cultures) . Some groups will choose a very efficient manner of distributing water , while others prefer distribution that , while not as efficient as possible , will ensure equity or justice in apportionment . In general terms , equity loses out to efficiency as climates become more arid and water is scarcer [19]. Certain kinds of documents permit this kind of analysis :

4 . *Inquests* . There is some documentation in which Muslim irrigators are asked by christian officials for details concerning the nature of water allocation arrangements . The most detailed is that of Gandia (1244) in which allocation of river water among various settlements is specified [20].

5 . *Litigation* . In court cases from the fourteenth and fifteenth centuries (in the kingdom of Valencia , for example) , irrigators gave testimony as to the nature of operating procedures of their communities and canals . The testimony of Muslim irrigators was , in certain areas , particularly valued because it was felt that they had access to the oldest (and therefore the most legally valid) information [21].

6 . *Ordinances of irrigation communities or procedures of the municipally administered canals (as recorded in municipal ordinances)* . such medieval ordinances may or may not faithfully reflect practice in Islamic times . Although ordinances provide detailed information about operating procedures, the administrative model underwent a significant change , as I will discuss below .

7 . *Arabic sources* . very few survive . One of the most useful is the record

19 . Noted by many students of irrigation , beginning with Jean Brunhes'classic comparative study of irrigation systems in southern Spain and North Africa (*L' Irrigation , ses conditions géographiques , ses modes et son organisation dans la péninsule ibérique et dans l'Afrique du Nord* , Paris , 1902) .

20 . Roque Chabas , *Distribucion de las aguas en 1244 Y donaciones del término de Gandia por D. Jaime I* (Valencia , 1898) .

21 . On the use of litigation documents to reconstruct the operating procedures of irrigation systems , see Glick , *Irrigation and Society in Medieval Valencia* , passim . on the testimony of Mudejar irrigators , Glick , "Hidraulica i politica hidraulica a la Gandia de Joanot " , in press .

of the settlement of a water dispute on the Palancia river in 1223 [22]. There are also quite a few documents from late medieval Granada which survive in Spanish translations made directly after the conquest of 1492 [23]. Some additional material of a notarial nature survives in Arabic documents of late medieval Mudejars [24]. Historical , geographical and even literary sources provide diffuse materials , some of which is surprisingly interesting and most of which is difficult to interpret because we are dealing mainly with anecdotes whose technical context is not provided . For example , Ibn Bassam claims to quote *a philosopher* (possibly *Aristotle* , according to Vernet) on the biophysics of the testicles which , the philosopher says , function like to counterweights helping to keep the body in equilibrium , just like *the weights which hang from the gates placed in irrigation canals , which open when there is a lot of water and close if there is only a little ; if one cleaves too much , more weight is placed on the other* [25]. The hydraulicist seeking to interpret this passage has little to go on , except that , in a general sense , all manner of devices were used to ensure that currents of irrigation water maintain their traditionally-established proportionality . These homespun devices of traditional technology rarely appear in formal treatises .

8 . Geographical distribution of technical terms . Elsewhere I have remarked that the creation of a linguistic Atlas of irrigation terms in the Islamic world (after the fashion of the Linguistic Atlas of Andalusia) would be a powerful tool in the interpretation of irrigation history [26]. Certain terms , widely distributed throughout the Islamic world , establish the historical filiation of the practices represented as well as suggesting the routes of their diffusion . In particular , the terms for irrigation turn , which in Spain are all Arabisms (e. g , *dula* , Arabic *dawla* ; *ador* , Arabic *daur* ; *martava* , Arabic , *martaba*), record specific families of operating procedures . The same is true of

22 . See Glick ,*Irrigation and Society in Medieval Valencia* , pp . 198 - 199 .

23 . As examples , see the sixteenth - century spanish translations of fourteenth - century Arabic documents relating to the division of the Abrucena river reproduced by Manuel Espinar Moreno , " Reparto de las aguas del rio Abrucena (1273? - 1420 , " *Revista del Centro de Estudios Historicos de Granada y su Reino* , 2nd epoch ,1 (1987) . 69 - 94 , on pp 89 - 94 .

24 . For example ,Angel Gonalez Palencia , " Notas sobre el regimen de aguas en la region de Veruela en los siglos XII y XII , " *Al - Andalus* , 10 (1945) , 79- 88 .

25 . Cited by Juan Vernet , " Perdigon : Los conocimientos de un hombre culto en la Zaragoza del siglo XI " (typescript) .

26 . Thomas F. Glick , "El sentido arqueologico de las instituciones hidraulicas.Regadio bereber y regadio español , " in *II Jornadas de Cultura Islamica* (note 18 , above) , pp . 165 - 171, on p. 170 .

measurement units (e.g .,Valencian *fila* ; Arabic *Khaiṭ*) [27]. To map them would make possible not only comparative study but also the reconstruction of systems for which there is no Islamic period documentation . The creation of such a linguistic atlas would not be difficult because questionnaires could be circulated through the irrigation bureaus of ministries of agriculture in the various countries in question .

3 . Water Law .

The formal law of water , whether Roman , Islamic or any other , encodes widespread traditional norms and practices which were fairly standard , common to all civilizations of antiquity and widely diffused throughout the Mediterranean basin.Specific practices in Islamic Spain and North Africa , however , may be presumed to represent not norms of Islamic law but rather those of Late Roman Provincial Law which in Crone's conception refers to non-Roman law or , rather Roman law with inflections or modifications reflecting the customary practices of the indigenous communities of the Roman empire [28]. Problems of interpretation here are massive , inasmuch as such regional variations are thinly documented . Two examples of this kind of problem will suffice . First is the much commented Latin inscription at Lamasba (Ain Merwana , Algeria) , which records an irrigation turn at a military colony which most likely embodies the practice of local Berber irrigators , with some patina of Roman law on top of it (but that patina might just have consisted in the formalization of in writing of a customary practice [29]. Second , is the ethnographic study of traditional Berber irrigation systems in the Atlas and anti-Atlas which establishes the priority of upstream irrigators over those downstream which contravenes the norms both of Roman riparian law *and* of Islamic water law [30]. Here is an appropriate example of the persistence of provincial custom which differs considerably from the wider systems of legal norms in which they were implanted .

It seems quite clear that certain provisions of *ḥadīth* or *shari'a* relating to water law reflect not the momentary whim of the Prophet or a Caliph , but

27. On Arabisms in Spanish irrigation terminology , see Glick , *Irrigation and Society in Medieval Valencia* , PP. 217 - 229 .

28 . Patricia Crone , *Roman , Provincial and Islamic Law : The Origins of the Islamic Patronate* (Cambridge , 1987) , especially PP . 1 , 15 .

29 . Brent D. Shaw , " Lamasba : An Ancient Irrigation Community , " *Antiquités Africaines* , 18 (1982) , 61 - 103 ; Miquel Barcelo , " La questio de l'hidraulisme andalusi , " in *Les aigues cercades* (note 16 , above) , PP. 9 - 36 , on P . 16 ; and Thomas F. Glick , " Las técnicas hidraulicas antes y después de la conquista , " in *En torno al 750 aniversario : Antecedentes y consecuencias de la conguista de Valencia* , 2 vols . (Valencia , 1989) , I , 53 - 71 , on PP. 62 - 63 .

30 . Glick , " Sentido arqueologico " (note 26 , above) , P . 167 .

rather give " norm and form " to local custom . Thus Muhammad's stricture that the right to water is not unlimited for any individual but extends only to the watering of a field to the depth of the irrigator's ankles no doubt reflects a customary norm and not his *ad hoc* invention [31]; this *ankle rule* , incidentally , is current in customary irrigation in southern Spain , an inheritance of Islamic custom , in this case . Likewise , the fact that Umar, when establishing land values for the *Kharāj* used different criteria for rating lands and crops in parts of Syria and Iraq , may reflect not only his own fiscal concepts but , more likely , preexisting legal structures , reflecting provincial law in the Byzantine and Sassanid empires [32]. Mawardi states that Umar took into consideration four ways in which crops received water . But tax codes in antiquity had not only taken such distinctions into account but used them in order to encourage irrigation , as in the laws of Diocletian (fourth century A.D.) which some authors have portrayed as a stimulus to the diffusion of norias [33] .

Some further particulars may be gleaned from the *Nawāzil* of al - Wansharisi , a collection of *fatwas* by a fifteenth-century Algerian jurisprudent , reflecting Andalusi practice [34]. Two of the *fatwas* deal with the issue of priorities of water right and in each case al - Wansharisi invokes the very widespread and ancient principle or Roman (and other) law that antiquity (of possession) creates the right (the *first in time , first in right* principle of *prior appropriation*) . In one case , hadith is cited , but no doubt this is an instance of a Muslim sanction applied to an old and universal principle [35]. Another decision relates to whether a *waqf* may sell rights to excess water that it does not need . Wansharisi says it may [36]. This decision may well have as its referent the particular hydrological situation of certain areas of North Africa and Spain where the alienation of water is customary (wherever water is distributed by unit of time) ; such a principle could not be applied generally because in systems (which I have called *Syrian* on the model of the allocation principle of the Barada river in the Ghuta of Damascus) where water is distributed with no measure of time , even usufruct cannot be alienated . A final example deals with the form of irrigation turns . Here Wansharisi in fact invokes customary , not Islamic , law when he observes that by consensus *(ijmā'a)* irrigation turns proceed from top to bottom , that is , from the head of the canal to the tail , a

31 . Al - Mawardi , *Les statuts gouvernementaux (Ahkam al - Sultaniyya)* , E . Fagnan , trans . (Algiers , 1915) , P . 158 .

32 . *Ibid* . , PP . 312 - 315 .

33 . John Peter Oleson , *Greek and Roman Mechanical Water - Lifting Devices : The History of a Technology* (Toronto , 1984) , P . 379 .

34 . Lucie Bolens , " L'irrigation en al - Andalus : Une société en mutation , analyse des sources juridiques (Les ' Nawazil ' d ' al - Wansharisi) , in *El agua en zonas aridas* (note 15 , above) , I , 71 - 94 .

35 . *Ibid* . , PP . 80 , 84 .

36 . *Ibid* . , P . 79 .

practice reflected in many north African and Spanish irrigation systems [37].

4 . Two administrative models .

The Christian successor irrigation systems of the later middle ages display two models of administration , one tribal , the other municipal . The tribal model is documented directly in the case of irrigation systems in Mudejar communities where councils of elders *(shyūkh)* are depicted as making administrative decisions . In canals established by Muslims but settled wholly or mainly by Christian settlers a different administrative model had to be substituted for norms of tribal governance , because the christians , of course, lacked such structures . Thus autonomous irrigation communities were organized like craft guilds with similar officers holding authority delegated by the entire community , enforced by a structure of monetary fines , a system which was surprisingly successful at replicating tribal social solidarity and a consensual , customary system of social control in the limited domain of water allocation . The second model is found in municipally - controlled canals : typically a small town with one main canal (acequia madre) whose administration is in the authority of the town council . It is clear here that the irrigation officials are modeled after their Islamic predecessors : namely the *ṣāḥib al - sāqiya (Çavacequia)* in medieval Aragon and Valencia) , the *amīn al - mā ' (alami* of Elche and Novelda) or , in Andalusia , the *qāḍi al - ma (alcalde de las aguas* , in Castilian) [38].

In Christian medieval practice , the models tended to become blurred and the *séquiers acequieros* in autonomous and municipally controlled systems had very similar attributes : they had (like all dependencies of the *qaḍā')* unipersonal jurisdictions and could impose fines summarily for all but major offenses . To return to Muẓaffar and Mubārak , they could not have split a jurisdiction in the huerta of Valencia ; each must have been ṣāḥib of one *sāqiya* . The alternative , some kind of centralized irrigation bureau set up ephemerally by the Amirids , would have been extremely atypical , for as we have noted , control of irrigation in al - Andalus was local . Although the evidence we have for irrigation in al - Andalus is mostly of an inferential nature , archeological evidence supports this picture and no documentary evidence contradicts it . The nature of post - conquest Christian institutions has direct bearing on its Islamic predecessor because of the ultra - stable nature of this kind of institution . Post - conquest evidence can therefore be used as if it were an archeological artifact [39].

37 . *Ibid* . , P . 80 .

38 . Glick , *Irrigation and Society in Medieval Valencia* , PP . 198 - 206 .

39 . Glick , " Sentido arqueologico " (note 26 , above) .

5 . *Hydraulic Technology* : Some Observations

I have written elsewhere about recent developments in the history of hydraulic technology in al-Andalus [40]. Here I wish to refer only to two techniques , the noria and the water-driven mill , in order to focus on problems of analysis and interpretation of very disparate evidence .

(a) Geographical distribution of norias . The animal - powered noria was virtually ubiquitous in Spain until the completion of rural electrification in the 1940S and 50 S . Since that time , it has virtually disappeared and all that can be studied in the field are the physical characteristics and distributions of the wells to which they were attached . The noria was a technique closely identified with the Arab conquests as a medium of diffusion . In its most common form , a hydraulic wheel moved by animal traction which lifts water from a wheel by an endless chain of pots , it was probably developed in late antiquity in Egypt . The Arabs then diffused it east to Spain and west to northern India in the course of their conquests and colonization . Thus the distribution and incidence of noria sites might well be expected to correlate with density and longevity of Muslim settlement .

Therefore geographical distribution is an important consideration , inasmuch as wherever and whenever the noria was introduced on a large scale it enabled single family farming units to make the transition from subsistence to market agriculture , creating thereby a series of a small agricultural revolutions along the path of its diffusion . The *Libros de repartimiento* are disappointing when it comes to norias ; relatively few are mentioned , possibly because of their very universality . Therefore , we have no notion of the distribution of norias at the beginning of Christian settlement .

In 1918 the Ministerio de Fomento surveyed water resources throughout Spain , as a result of which norias were actually counted [41]. It is clear that the methods of counting varied from province to province and that one cannot , in each case , be sure whether all norias were counted or whether traditional (*norias arabes*) were aggregated with iron or electrified norias . Where possible I have counted animal - traction norias , whether made of wood or iron. Table 1 is a rank - ordering of the fifteen provinces recording the greatest number of norias . For some provinces or judicial districts (*partidos judiciales)* no figures at all are supplied for norias . Therefore when comparing provinces or regions of the peninsula it is difficult to know what exactly is being compared .

40 . Thomas F . Glick , " Regadio y técnicas hidraulicas en al - Andalus : Su difusion segun un eje Este - Oeste , " in *La caña de azucar en tiempos de los grandes descubrimientos , 1450 - 1550* (Motril , 1989) , PP . 83- 98 .

41 . *Medios que se* utilizan *para suministrar el riego* , 2 vols . (Madrid , 1918) .

Table 1
Distribution of norias , 1918
(Rank order by Province)

1.	Ciudad Real	21.006
2.	Castellon	4 . 083
3.	Baleares	3 . 540
4.	Toledo	2 . 750
5.	Valencia	2 . 000*
6.	Zamora	1 . 552
7.	Madrid	1 . 432
8.	Caceres	1 . 010
9.	Valladolid	842
10.	Almeria	668
11.	Cordoba	647
12.	Alicante	566
13.	Gerona	505
14.	Murcia	503
15.	Jaén	452

* Estimate of reporter .

Source : Ministerio de Fomento , *Medios que se utilizan para suministrar el riego* . 2 vols . (Madrid , 1918)

Nevertheless the gross figures reveal some interesting patterns . First , the provinces of New Castile (Table 2 : Ciudad Real , Toledo , Madrid , Cuenca and Guadalajara) had by far the greatest concentration of norias , 22 , 553 , with the Levant provinces of Castellon , Valencia , Alicante and Murcia in second place with 7152 (Table3) [42]. The Levant ,of course , is a place more characterized by gravity flow irrigation in canals,whereas in La Mancha (Ciudad Real and Toledo) the preponderance of all irrigation was by noria . The third-ranked region includes Catalonia and the Balearic islands (4453;Table4).

Table 2
Distribution of norias , New Castile

1.	Ciudad Real	21 . 006
2.	Toledo	2 . 750
3.	Madrid	1 . 432
4.	Cuenca	336
5.	Guadalajara	29
	TOTAL	22 . 553

42 . The figure for Murcia seems unusually low

Table 3
Distribution of norias , Levant

1.	Castellon	4 .083
2.	Valencia	2 . 000
3.	Alicante	566
4.	Murcia	503
	TOTAL	7 . 152

Table 4
Distribution of norias , Catalonia / Baleares

1.	Baleares	3 . 540
2.	Gerona	505
3.	Tarragona	387
	TOTAL	4. 432

It is interesting to note that Leon (Table 5) with 2195 norias counted ranks far ahead of the Islamic heartland of Andalusia (Table 7) , with only 1810 norias , although this total is undoubtedly too low because only figures for four provinces are provided in the survey . Even Old Castile (Table 6 ; 1259 norias) compares favorably with Andalusia , and the province of Valladolid (842 norias) ranks higher than any Andalusian province . In Leon, more than seventy per cent of all norias were located in the province of Zamora,which was a kind of transit point for the diffusion of Islamic techniques northward to the Christian heartland . The city was famed for its *aceñas (sāniya / s)* , vertical water mills located in the city of Zamora on the Duero river . It may well be that the region of Tortosa which accounts for nearly half (176) of Tarragona' s 387 norias , played a similar role in the diffusion of Islamic techniques to Catalonia .

Table 5
Distribution of norias , Leon

1.	zamora	1 . 552
2.	Leon	338
3.	Salamanca	305
	TOTAL	2 . 195

Table 6
Distribution of norias , Old Castile

1.	Valladolid	842
2.	Burgos	133
3.	Palencia	108
4.	Logroño	67
5.	Segovia	57
6.	Soria	52
	TOTAL	1. 259

Table 7
Distribution of norias , Andalusia

1.	Almeria	668
2.	Cordoba	647
3.	Jaén	452
4.	Granada	43
	TOTAL	1. 810

What generalizations can be drawn from these figures? *First* , there is a relationship between the relatively high density of Muslim settlement in new Castile (particularly La Mancha) , the Levant , and the Balearic islands and the incidence of norias there . *Second* , certain regions such as Catalonia and old Castile received the technique by diffusion and not via continuity with Muslim sites [43]. *Third* , the intensity of noria use in La Mancha is no doubt owing more to its peculiar hydrological circumstances (shallow and high - yielding water tables) than to the density of Muslim settlement per se . Nevertheless , from archeological evidence we know that in this area the Muslims replaced a Roman canal - based irrigation system with another one based entirely on wells and norias [44].

(b) Mills . In contradistinction to the case of norias , mills are heavily documented in the *Libros de repartimiento ;* because of their value to the state as taxable monopolies , none escaped the notice of the king's surveyors . The

43 . Guichard notes as an open question the significance of the diffusion of the noria well beyond areas of dense and long - lived Muslim settlement ; *Les Musulmans de Valence* (note 13 , above) , I , 16 - 17 .

44 . Almudena Orejas Saco del Valle y F. Javier Sanchez Palencia " Obras hidraulicas romanas y explotacion del territorio de la provincia de Toledo , " in *El agua en zonas aridas* (note 15 , above) , I , 43 - 67 , on P . 59 .

Repartiment of Valencia , for example , lists several hundred mills , including forty three in the huerta of Valencia alone [45]. The problem is that there is no way to tell what kind of mills these were . In the present state of knowledge , all are presumed to have been horizontal mills because there is no clear documented instance of a vertical mill , nor any archeological remains of one in the Valencia Community . The Arabs surely introduced the vertical mill in al- Andalus both for the milling of grain and for industrial uses . The vertical mill diffused northward into Castile , with the name of *aceña* (from Arabic , *sāniya*) which always denotes verticality in medieval Castilian documentation . Not only were *aceñas* semantically differentiated from horizontal mills *(molinos de rodezno)* but their geographical distribution followed a characteristic pattern , with *aceñas* located on large rivers and horizontal mills on smaller streams , owing to the different hydraulic requirements of each [46].

There is a question , therefore , of why vertical mills were apparently unknown in medieval Valencia and what was the nature of the industrial mills (for fulling , mainly) which are documented there [47]. In the huerta of Valencia , where all mills were built on irrigation canals which supplied water to them with optimal head , under controlled velocity , the solution to the need for more power was simply to add additional millstones in the same mill house ; therefore some mills had three , four or up to eight horizontal millstones all grinding at the same time , doing the work that a large vertical mill could do, but without the cost of building and maintaining gearing mechanisms . Still , although it is possible to run a trip - hammer off a horizontal wheel , the gearing is complex enough to discourage this method .

Undershot vertical mills run well on irrigation canals , but none are documented There is an interesting literary reference to an undershot mill in Waluta (probably *Adrà*) , Mallorca , another area where all of the documented medieval mills (162 of which are mentioned in the *Repartiment*) appear to have been horizontal [48]. The interest of this mill , described by al - Qazwini , quoting a now lost passage from *al - Udhri* , is that when water was scarce it

45 . Vincenç , M. Rosssello , " Els molins d' aigua de l' Horta de València , "in *Los paisajes del agua* (Valencia / Alicante , 1989) , PP . 317 - 345 , on P . 319 .

46 . Luis Miguel Villar Garcia , *La Extremadura castellano - leonesa : Guerreros , clérigos y campesinos (711 - 1252)* (Valladolid , 1986) , P . 335 , note 123 .

47 . I have discussed this problem in " Molins d' aigua a l' Horta medieval de València , " *Afers* , 9 (1990) , 9 - 22 .

48 . On traditional horizontal mills in medieval Mallorca , see Miquel Barcelo " Els molins de Mayurqa , " in *Les Illes Orientals d' Al - Andalus* (Palma de Mallorca , 1987) , PP . 253 - 262 , a study of the mills mentioned in the *Repartiment* ; he does not mention *Qazwini's* mill . See also , Helena Kirchner , et al ., " Molins d' origen musulma a Banyalbufar , " *Estudis Balearics* , IV , no . 21 (June 1986) , 77 - 86 .

could be converted from an undershot into an overshot wheel [49]. The passage reads as follows: [50]

> when the water which moves it is scarce they take a thick log of some ten palms in circumference by seven cubits long. They saw it into two halves and hollow out each half from one end up to half a cubit before reaching the other. Both pieces are joined and in the solid end they make a hole as wide as a donkey's hoof . They erect it over the canal so that the end which has the hole rests on the wheel[51]; the water exits forcefully (*bi'l - quwwa*) through the hole in the log , strikes the teeth (*amshāṭ*) of the wheel , and mill begins to turn .

The Passage is interesting because it demonstrates that vertical mills were perceived as more efficient than horizontal ones and that local millers knew the technology . In any area like the Balearic Islands where the noria was widely implanted , all local carpenters knew how to make *dawlab / s* .

49 . Al - Qazwini , *Kosmographie* , ed . Wustenfeld , II , 381 . See comments on this mill by E . Weidemann , " Uber ein arabisches , eigentümliches Wasserrad und eine Kohlenwasserhaltige Höhle auf Mallorca nach al- Qazwini , " Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften , 15 (1916) , 368 - 370 (drawing on P . 369) ; R . J . Forbes , *Studies in Ancient Technology* , vol .II (Leiden , 1965) , p . 92 ; and Terry Reynolds ,*Stronger than a Hundred Men : A History of the Vertical Water Wheel* (Baltimore , 1983) , P . 119 .

50 . Here I follow the translation of José Alemany Bolufer , *La geografia de la Peninsula* Ibérica *en los escritos arabes* (Granada , 1921) , p . 135 , emending it from the Arabic text where the context requires .

51. Bolufer translates *rodete* which would indicate a horizontal wheel ; but the Arabic text has *dawlab* which surely indicates a vertical wheel with a horizontal axis , and that is how wiedemann draws it . Both Reynolds and Forbes give the impression that this was a standard horizontal mill convertible into a vertical overshot mill .