Hidden Depths: The Wicked Problem of Groundwater Management in a Spanish Aquifer, 1964–1990

Sarah Hamilton
University of Bergen

Introduction

Rain rarely falls on the Spanish plains. For more than two millennia, successive governments on the Iberian Peninsula have adapted to irregular precipitation patterns and regional aridity through the construction of vast waterworks, from stone aqueducts and hand-dug wells to modern hydraulic dams and long-range water transfers. During the dictatorship of Francisco Franco (1939–75), the construction of large dams and canals played a crucial role in centralizing state power over land, resources, and people.[1] While Franco's engineers began reshaping the country's surface waters even before the conclusion of the civil war (1936–39), however, the vast majority of Spain's fresh water remained out of their reach for another thirty years. Beginning in the mid-1960s, the introduction of hydraulic drills, rural electrification, and international expertise allowed the Spanish state to begin large-scale groundwater exploitation, physically and economically transforming some of Spain's most underdeveloped regions, producing vast commercial harvests in formerly unproductive fields, and quenching the thirst of expanding urban populations.

Like other subterranean resources, groundwater is both invisible and finite. Worldwide, over the course of the twentieth century new technologies and knowledge provided access to millions of cubic hectares of groundwater that had accumulated in aquifers over the course of centuries or millennia. As the water was pumped to the surface the gradual, often imperceptible exhaustion of the aquifers and the limitations of hydrogeological knowledge allowed stakeholders to assert conflicting claims according to their economic and political interests. Scientists and water managers pursuing long-term stability struggled to calculate aquifers' volumes, their rates of recharge from the surface, their interactions with ecosystems and human communities, and their susceptibility to overdraft or contamination. Today, even the best models of the most heavily studied aquifers remain far from precise and rely upon estimated, projected, partial,

[1] Erik Swyngedouw, *Liquid Power: Contested Hydro-Modernities in Twentieth-Century Spain* (Cambridge, MA, 2015).

The Journal of Modern History, volume 94, number 2, June 2022.
 https://doi.org/10.1086/719491

and subjective data.[2] Stakeholders often amplify this uncertainty in their rhetoric and policy proposals, exaggerating the flaws of existing models to achieve their desired policy outcomes. Irrigators and developers optimistically project economic windfalls from water use and tout the supposed inexhaustibility of the supply, while conservationists urge restraint to stave off potentially permanent declines in the water table and damage to adjacent bodies of water. In policy-making parlance, groundwater use is a "wicked problem," virtually insoluble due to its complexity, scientific uncertainty, stakeholders' incompatible objectives and worldviews, and the serious and irreversible repercussions of any actions that are taken.[3] Politically and economically motivated campaigns to discredit unfavorable scientific arguments and cast doubt upon adverse outcomes exacerbate confusion among the public and stymie efforts to forge effective policy solutions.

This article explores the wicked problem of groundwater management in the context of Spain's first large-scale hydrogeological undertaking: the development of the Almonte-Marismas aquifer system in the Andalusian province of Huelva between 1964 and 1990. Following preliminary research carried out in collaboration with the United Nations' Food and Agriculture Organization (FAO), multiple agencies within Franco's Ministry of Agriculture issued wildly optimistic estimates of the aquifer's ability to breathe new life into one of the most arid and impoverished regions of the country. Those estimates served as the basis for heavy state investment in groundwater exploitation and stimulated a surge of private interest in touristic development and irrigated agriculture. Simultaneously but incompatibly, an international conservation campaign successfully secured legal protections for what would become Doñana National Park, an ecologically complex, partially groundwater-dependent space immediately adjacent to the lands under development. Citing the lack of knowledge about the impacts that groundwater extraction could have on the park's ecosystems, natural scientists and conservationists called for a precautionary regulatory approach that would limit pumping pending further research. Local politicians and landowners, conversely, used the scientific uncertainty surrounding the aquifer to advocate for continued development, arguing that the mere possibility of ecological risks could not stand in the way of economic growth.

The Almonte-Marismas case underscores the problems inherent in the production and application of knowledge about a hidden resource and demonstrates the myriad ways in which state and private actors can generate, manipulate, and conceal scientific research to advance their own agendas. Groundwater's invisibility

[2] FAO, *Report of the FAO/UNDP—Government of Spain Seminar on the Role of Groundwater in the Optimal Utilization of Hydraulic Resources, October 18–23, 1971*, irrigation and drainage paper 18 (Rome, 1973), 15.

[3] The concept of the "wicked problem" was first introduced by Horst W. J. Rittel and Melvin M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4 (1973): 155–69.

adds a new facet to existing work by David Michaels, Robert Proctor, Londa Schiebinger, Naomi Oreskes, Erik Conway, and others regarding the politically motivated creation and wielding of uncertainty.[4] Understanding the historical roots of groundwater policy, moreover, is vital in an era in which surface water is becoming scarcer, forcing states and communities around the world to rely more heavily on underground reserves. In the first decades of the twenty-first century, more than 11 percent of Europe's population and 17 percent of its territory are affected by water scarcity, and these percentages are likely to increase as temperatures continue to rise.[5] Political and legal water management strategies that were established on the basis of flawed data, exaggerated uncertainty, and the values and priorities of previous generations must adapt to these changing physical conditions. In Spain and beyond, the false perception that groundwater policy is—or can be—based on incontestable, objective scientific conclusions masks the ethical and economic values that underlie it.

Groundwater and the Spanish State

Geographer Ricardo Macías Picavea, writing in 1899, described Spain as "a territory that could be civilized exclusively at the expense of great hydraulic works, of national character, reconstructive, almost geological."[6] Generations of twentieth-century Spanish politicians, from the socialists of the Second Republic to the technocrats of the late Franco regime, adhered to this principle in their pursuit of Spanish modernization through the rationalization of the country's water resources. Public investment in water management projects for the purposes of irrigation, flood control, and hydroelectric generation reached its zenith under the nationalist Franco dictatorship, during which massive dams and water transfers served as highly visible reminders of the state's power and technological prowess.[7] Pursuant to autarkic policies during the 1940s, the Ministry of Public Works described irrigation as a panacea for a host of social and economic woes and focused its efforts on building dams and reservoirs in order to increase the production of staple crops. The state's limited resources meant that few significant

[4] David Michaels, *Doubt Is Their Product: How Industry's Assault on Science Threatens Your Health* (Oxford, 2008); Robert Proctor and Londa L. Schiebinger, eds., *Agnotology: The Making and Unmaking of Ignorance* (Stanford, CA, 2008); Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York, 2010).

[5] "Addressing the Challenge of Water Scarcity and Droughts in the European Union" (Communication from the Commission to the European Parliament and the Council, Brussels, July 18, 2007).

[6] Ricardo Macías Picavea, *El problema nacional* (Madrid, 1899), 318–20.

[7] Erik Swyngedouw, "The Scalar Politics of Franco's Hydro-Social Dream for Spain, 1939–1975," *Transactions of the Institute of British Geographers* 32 (2007): 9–28.

projects were actually completed during this period, but those that were featured heavily in the regime's propaganda at home and abroad.[8]

Once the dams were constructed, the practical work of turning arid plains into croplands was carried out by the National Colonization Institute (Instituto Nacional de Colonización, or INC), the rural development agency of the Ministry of Agriculture. As originally conceived, the INC provided previously underutilized land along with equipment and startup funds to carefully selected landless peasants in exchange for a promise to keep their fields in good condition and to repay a portion of the state's expenses. Over the course of the 1940s, the INC's mandate expanded to include research on crop sciences and agricultural techniques, expropriation of underproducing estates, leveling and preparing fields, and planning and constructing irrigation canals to carry water from the new reservoirs. In this manner the INC served as the primary instrument of what the regime described as "a policy of internal colonization in which social progress is based, above all, on the realization of the land's potential wealth through the execution of appropriate public works and labors."[9] The process, Franco explained, was intended to redistribute "Spain's best lands" to a new class of small, independent farmers, "creating [the lands] first with our effort, damming or elevating the water of our rivers and creating heritage that will not be the ruin of the workers. This," he went on, "is our agrarian reform: to transform the lands in order to redistribute them, to demand that men can work year-round, to require crop intensification proportionate to the wealth of the land."[10] Despite the lingering physical and economic devastation from the civil war, in its first decade of existence the INC succeeded in doubling the area of irrigated land nationwide.[11]

When a Cold War alliance with the United States brought Spain a windfall of economic and technological aid, much of it went toward additional hydraulic projects. Over the course of the 1950s the United States sent Spain $1.5 billion

[8] "Ley Aprobando el plan de Obras Públicas," Boletín Oficial del Estado 115, April 25, 1939.

[9] INC, *XXV Aniversario de la creación del Instituto Nacional de Colonización: Delegación Regional de Albacete* (Ministerio de Agricultura, 1964), 2.

[10] Francisco Franco, "Discurso a los campesinos del Campillo del Rio, Pronunciado en Campillo del Rio, Jaén, 21 abril 1961," in *Discursos y mensajes del Jefe del Estado, 1960–64* (Madrid, 1964), 146–47.

[11] "Decreto Organizando el Instituto Nacional de Colonización," Boletín Oficial del Estado 300, October 27, 1939; "Ley de Bases para Colonización de Grandes Zonas," Boletín Oficial del Estado 25, January 25, 1940; "Ley Aprobando el plan de Obras Públicas"; "Decreto por el que se autoriza al Instituto Nacional de Colonización para la compra de determinadas fincas," Boletín Oficial del Estado 218, August 6, 1942; "Ley sobre expropiación forzosa de fincas rústicas, con la debida indemnización, previa declaración de interés social," Boletín Oficial del Estado 118, April 28, 1946; "Ley sobre colonización y distribución de la propiedad de las zonas regables," Boletín Oficial del Estado 112, April 22, 1949.

in loans, grants, food, textiles, and machinery and provided diplomatic support for the country's reintegration with Western political and economic networks. By 1958, US influence had facilitated liberal technocrats' ouster of the postwar autarkists from Franco's cabinet, and the new ministers negotiated Spain's accession to the Organization for European Economic Co-operation, the World Bank, and the International Monetary Fund. Between 1959 and 1974 they steered the country's economic policy away from a focus on agricultural self-sufficiency and toward stimulation of foreign investment, exports, and international tourism, generating rapid economic growth across all sectors in a phenomenon widely referred to as the "Spanish miracle."[12] The new revenue enabled the state to increase its investments in public works, including land reclamation, hydroelectric generation, urban development, and agricultural intensification. In 1961, reservoir capacity was nearly 20 percent of the total volume of Spanish rivers, but just a decade later that fraction had doubled. Along with an expanding network of irrigation canals came plastic greenhouses, fertilizers, tractors, chemicals, and other accoutrements of the Green Revolution, first on INC test plots and then on colonized and private farms. The value of Spanish agricultural production grew exponentially, even as the significance of the primary economic sector—those industries involved in the direct exploitation of natural resources—declined relative to those of the secondary (manufacturing) and tertiary (service) sectors.[13]

The Franco regime's interest in harnessing Spain's natural resources had long encompassed groundwater. State engineer Carlos Morales Antequera assured radio listeners in 1945 that "we have the happy circumstance that only a few meters

[12] Ronald H. Chilcote, "Spain and European Integration: Heavy Industry in Economic Development," *International Affairs (Royal Institute of International Affairs 1944–)* 42, no. 3 (1966): 42; Rodney H. Mills, "The Spanish 'Miracle': Growth and Change in the Spanish Economy, 1959 to mid-1965," staff economic studies, Board of Governors of the Federal Reserve System, 1966; Eric N. Baklanoff, "Spain and the Atlantic Community: A Study of Incipient Integration and Economic Development," *Economic Development and Cultural Change* 16, no. 4 (1968): 599; Julio Alcaide Inchausti, "Series históricas españolas 1898 a 1998," in *1900–2000: Historia de un esfuerzo colectivo. Cómo España superó el pesimismo y la pobreza* (Fundación Santander Central Hispano, BSCH, Editorial Planeta, 2000), 2:645–712; M. Teresa Sanchís Llopis, "The Spanish Economic 'Miracle': A Disaggregated Approach to Productivity Growth, 1958–1975," *Revista de Historia Económica—Journal of Iberian and Latin American Economic History* 24, no. 2 (January 2006): 413.

[13] James Simpson, *Spanish Agriculture: The Long Siesta, 1765–1965* (New York, 1995), 261; Jesús Alonso Millán, *Una tierra abierta: Materiales para una historia ecologica de España* (Madrid, 1995), 240, 263; Joaquín Melgarejo Moreno, "De la política hidráulica a la planificación hidrológica: Un siglo de intervención del estado," in *El agua en la historia de España*, ed. Carlos Barciela López and Joaquín Melgarejo Moreno (Alicante, 2000), 307; Pablo Corral Broto, "Expertise and Rural Protest against Industrial Pollution from Early to Miracle Years in Francoist Spain (1945–1965)," in *Naturaleza e cidades: O viver entre águas doces e salgadas*, ed. Silvério Gandara Gercinar (Goiania, Brazil, 2012), 214–31; Swyngedouw, *Liquid Power*, 261.

below our plants we have a wealth of subterranean waters which, conveniently elevated, can fertilize many thousand hectares, assuring winter harvests and producing extremely abundant summer ones." In the dry southeast, in particular, he reported that groundwater exceeded surface flows by a factor of "ten to one."[14] In reality, not only did Spain lack the tools and knowledge necessary to "conveniently elevate" its groundwater, it also lacked any empirical basis for Morales Antequera's confident claims. Spanish scientists possessed virtually no information about their subterranean landscape. The National Geological and Mining Institute (Instituto Geológico y Minero de España, or IGME) had never conducted nationwide hydrogeological or topographical studies and did not have even an approximate idea of the locations, volumes, depths, or economic potential of the country's aquifers. As late as the mid-1960s, according to hydrogeologist Rafael Fernández Rubio, aquifers were "great unknowns, about which there was hardly any specific information." What little data did exist was "almost always unpublished and difficult to access." Even aerial photography was relatively rare and subject to government censorship for military or strategic purposes: on one research trip, Fernández Rubio was detained for possession of aerial photographs and a topographic map and struggled to convince the local Civil Guard that he was not "a dangerous element."[15]

The absence of such basic information presented a major financial and practical impediment to large-scale groundwater exploitation. Legally, Spain's 1879 Water Law incentivized private development by making groundwater freely available to anyone who extracted it from a well on their property.[16] Practically, however, the high costs of labor and equipment for drilling wells, the absence of rural electricity or other cheap fuel sources to run pumps, and the elevated risk of failure and lost investment proved prohibitive. Thousands of hand-dug wells across the country attested to the fact that most rural Spaniards had a rough idea of where local sources of potable water lay close to the surface, but without solid hydrogeological data there was no way for would-be irrigators to know precisely where to place their wells, how deep to drill, or how much water could be safely extracted without compromising its quality or exhausting the supply. As a result, well into the 1960s Spanish groundwater extraction was carried out almost entirely via wind- and animal-driven pumps capable of drawing only small amounts of water from a depth of about ten meters. Such supplies were generally adequate for household use or as a short-term supplement in times of extreme drought but

[14] Carlos Morales Antequera, "Frente a la sequía," *Radio agricola* (Madrid, May 28, 1945).

[15] Rafael Fernández Rubio, "La hidrogeología en los años sesenta," in *Aportaciones al conocimiento de los acuíferos andaluces: Homenaje a Manuel del Valle Cardenete*, ed. Juan Carlos Ruebio Campos and Juan Antonio López Geta (Granada, 2002), 152–53.

[16] "Ley dictando disposiciones que se han de tener presentes respecto a la propiedad, uso y aprovechamiento de aguas," Gaceta de Madrid 170, June 19, 1879.

fell far short of the large volumes necessary to bring about significant economic change.

The same foreign aid that allowed the regime to expand hydraulic infrastructure on the surface, however, also brought into reach the sociotechnological arrangements necessary for large-scale groundwater use. Beginning in 1953 the United States facilitated the INC's access to electrical and diesel turbines, drills, pumps, engines, and center-pivot irrigation systems and supported training for Spanish scientists and technicians in their use.[17] While INC agents learned to operate their new equipment, IGME geologists attended training sessions in California and translated books on groundwater exploration and capture into Spanish. Together, over the course of a decade Spanish and American researchers carried out a preliminary hydrogeological survey of the national territory, tracing the general outlines of the country's major aquifers and prompting the head of the INC's groundwater division to optimistically predict an imminent ability to irrigate over a million additional hectares of land.[18]

IGME's survey served as the basis for its successful 1964 application to the FAO for the development of groundwater resources in "relatively poor regions within the Spanish territory, which were therefore more needy of this sort of assistance."[19] The FAO sent scientists from France, Nigeria, Brazil, Argentina, the United States, the Netherlands, Vietnam, and elsewhere to train Spanish "apprentices"—mining engineers, geologists, geophysicists, hydrologists, statisticians, seismologists, electronic technicians, draftsmen, and support personnel—as the country's first generation of groundwater experts. Some of the foreigners assisted agents at the INC, establishing test wells to measure the depth and quality of water in known aquifers. Others worked with IGME to conduct a barrage of seismic, magnetic, and resistivity tests; catalog existing wells and water points (sites where groundwater reached the surface in springs or seeps); and analyze aerial photography and field observations. In 1967 the international team synthesized all this preliminary data in a set of hydrogeological maps that highlighted the most promising sites for further development.[20]

[17] William M. Alley and Rosemarie Alley, *High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater* (New Haven, CT, 2017), 9.

[18] Alberto Benitez, *Captación de aguas subterráneas: Nuevos métodos de prospección y de cálculo de caudales* (Madrid, 1963); R. H. Pemberton, "Ground-Water Exploration in Spain," *Groundwater* 3, no. 3 (July 1965): 50; Andrés Murcia Viudas, *Investigaciones de aguas subterraneas en el sudeste español* (Madrid, 1966), 18.

[19] Agustín Navarro Alvargonzález, "La etapa del Proyecto FAO del Guadalquivir," in *Aportaciones al conocimiento de los acuíferos andaluces: Homenaje a Manuel del Valle Cardenete*, ed. Juan Carlos Rubí Campos and Juan Antonio López Geta (Granada, 2002), 18.

[20] Pemberton, "Ground-Water Exploration in Spain," 49–50; Juan Carlos Rubí Campos and Juan Antonio López Geta, eds., *Aportaciones al conocimiento de los acuíferos andaluces: Homenaje a Manuel del Valle Cardenete* (Granada, 2002).

FIG. 1.—Autonomous Communities of Spain. The box indicates the location of the Almonte-Marismas aquifer, magnified in figure 2. Color version available as an online enhancement.

Foremost among those sites was Andalusia's fifty thousand square kilometer Guadalquivir river basin (fig. 1).[21] The basin was selected for a combination of physical and socioeconomic factors: large, easily accessed aquifers underlay arid, almost entirely undeveloped lands that were home to one of the poorest populations in Western Europe. The average income in Andalusia was less than half that of the United Nations' standard for underdeveloped countries, and gross socioeconomic inequalities exacerbated the region's problems. A few wealthy families owned more than 90 percent of the land and used it for low-intensity farming,

[21] FAO, "Proyecto piloto de utilización de agua subterránea para el desarrollo agrícola en la cuenca del Guadalquivir: Informe sobre los resultados del Proyecto. Conclusiones y recomendaciones" (Rome, March 1972), 1, Biblioteca del IGME.

forestry, and hunting, while the rest of the sparse population scratched out a living as laborers or subsistence farmers.[22] As they did in many similarly poor regions of the country, IGME and the INC blamed the area's underdevelopment on the relative scarcity of surface water for irrigation, which prevented local farmers from benefiting from its long growing seasons, mild winters, and perennially sunny skies. In approving funding for further research the FAO concurred, noting that "the ability to develop Spain's Guadalquivir basin to its full potential depends, above all, on the volume of groundwater that can be used with economic efficiency."[23]

By 1969 the FAO teams had further narrowed the scope of their investigation to a triangle of land in the extreme southwest of the Guadalquivir basin (fig. 2). Bounded by the Guadalquivir River in the east, Seville in the north, and Huelva in the west, the area encompassed two distinct geomorphological landscapes underlain by interconnected aquifers. The *marismas*, a flat expanse of tidal marshes just west of the river, had highly saline clay soils that were seasonally flooded by distributary streams of the river. Below the marshes lay a large, shallow aquifer formed of saturated sand and gravel that was confined by impermeable layers of clay and stone above and below. This confinement created a slight artesian pressure that forced water up towards the surface and prevented precipitation and runoff from filtering back into the ground. North and west of the marshes lay the *arenas*, where sandy soils were vegetated with low brush, pine trees, and other hardy and drought-resistant plants. The aquifer beneath the sand was linked with that below the marismas, but the lack of clay confining strata meant that water could more easily permeate the surface and that the water there was not under artesian pressure. Preliminary studies convinced the FAO teams that the interconnected aquifers, known collectively as the Almonte-Marismas system, contained more than a million cubic hectares of fresh water. Aboveground, virtually the entire area was owned by a handful of families who had left the land largely undeveloped, while local villagers worked on small olive or grape plantations and cultivated forest resources in the arenas or grazed their cattle and horses in the marismas.

Implementing intensive, groundwater-irrigated agriculture on this complex landscape would require substantial additional research into the aquifers' characteristics and behavior. Since the advent of large-scale groundwater development in the late nineteenth century, water managers had been guided by the principle of a "water budget" that purported to set safe limits for extraction. In its simplest form,

[22] Ricardo Grande Covián, *Las marismas del Guadalquivir y su rescate* (Madrid, 1967), 23, 27–28; Rafael Leblic, "La agricultura en Huelva," *ABC-Sevilla*, March 23, 1973, secs. 17–25, 19; ICONA, "Informe: Plan General de Colonización de la Zona Regable Almonte-Marismas (Sevilla-Huelva)" (Madrid, 1975), 4–5, box 122, Fondo Documental de Montes.

[23] Quoted in EFE, "Investigaciones hidrológicas en la cuenca del Guadalquivir," *ABC-Sevilla*, February 16, 1965.

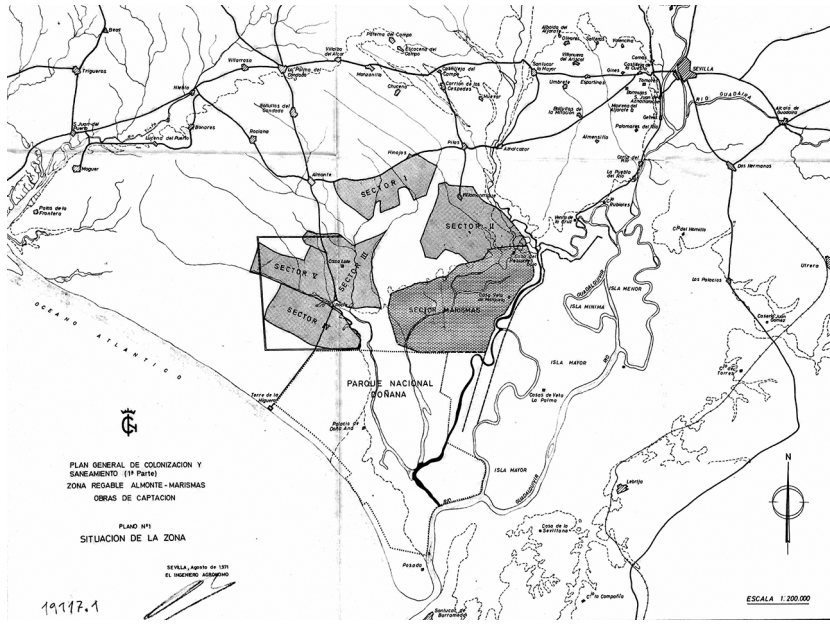

Fig. 2.—Almonte-Marismas Plan, 1971. Shaded areas represent lands that the INC planned to transform. The darkest sector ("Sector Marismas") indicates the area that would be "rinsed" with water from the Guadalquivir River; all other sectors were slated for groundwater-based development. Note the proximity of all sectors to Doñana National Park (Parque Nacional Doñana). Today two large, groundwater-irrigated rice plantations occupy more than 1,300 hectares within the Sector Marismas, while private lands to the west of the plan area, left blank on this map, are dominated by strawberry cultivation. Source: Ricardo Grande Covián, *Plan General de Colonización de la Zona Regable y de Saneamiento, Almonte-Marismas (Sevilla-Huelva)* (Sevilla: INC, September 1971), Proyectos INC signatura provisional 19117, [España] Ministerio de Agricultura, Pesca, y Alimentación (AC-MAPA).

a balanced water budget requires that water extraction not exceed the volume of recharge in a given year, leaving the aquifer in a state of dynamic equilibrium in which it gains and loses water continually (from precipitation, evaporation, etc.) without reducing its stored volume. Pumping water out of an aquifer more quickly than it can recharge from the surface upsets this balance, drawing down the water table and eventually causing wells to run dry. But planning for sustainable long-term exploitation also requires more specific analyses that take into account local variations in lateral flow rates, soil permeability, and interactions with surface water bodies. In the immediate vicinity of a well, rapid pumping creates a "cone of depression" in the water table (fig. 3). Water percolates slowly through the aquifer down the incline of this cone, toward the intake point, at a rate that may range from

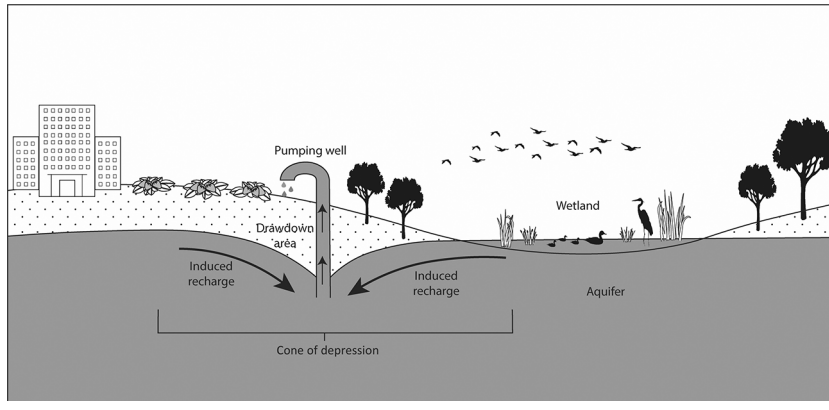

Fig. 3.—Impacts of pumping wells. Water flows down subterranean gradients into the cone of depression. If the well continues to pump more quickly than water can refill the drawdown area, the cone expands outwards and downwards until it intersects with and begins to draw from another body of water. Figure by author.

a few inches to a few feet per year. So long as the well continues pumping, the drawdown area expands outward and downward. If it sinks below the intake point, the well runs dry. If it intersects the cone of another well, the flow of both wells is impaired. If it reaches a local stream, it draws water from that stream; if it reaches a low-lying wetland, it draws water from the wetland; if it intersects the ocean, it draws saltwater into the aquifer, in a phenomenon known as "saline intrusion" that can contaminate the entire aquifer.[24]

Heavy groundwater pumping, then, can have a variety of serious ecological and economic impacts. It can deplete surface water bodies, reduce the quality of an aquifer's water, cause wells to run dry, and drive up the cost of further extraction as water users are forced to pump water from greater depths. In the case of the Almonte-Marismas aquifer system specifically, groundwater overdraft would lead not only to failed wells and wasted investments but also to changes in the surface water cycle and to saline intrusion from the Atlantic Ocean in the south or the brackish estuaries of the Guadalquivir in the east. The process of overdrawing an aquifer is a gradual one, however, and it is virtually impossible to link an individual well's rate of extraction to observable changes in the

[24] Charles H. Lee, "The Determination of Safe Yield of Underground Reservoirs of the Closed-Basin Type," *Transactions of the American Society of Civil Engineers* 78 (1915): 148–51; Charles V. Theis, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *Transactions, American Geophysical Union* 16, no. 2 (1935): 519–24; Charles V. Theis, "The Source of Water Derived from Wells," *Civil Engineering* 10, no. 5 (1940): 277–80.

surrounding environment as they are occurring. Although water budgets are intended to prevent such situations, a budget derived from flawed estimates of an aquifer's volume and rate of recharge, or an absence of data from individual wells about the volumes being extracted and the depths at which water is being obtained, can obscure the presence of growing problems. By the time those problems become evident on the surface in the form of desiccated wetlands and faltering wells, the changes may be irreversible. An accurate water budget derived from thorough, consistent, and reliable data is thus essential to ensuring the long-term ecological and economic sustainability of groundwater extraction.

According to the FAO's analysis, the near absence of recharge from the surface to the aquifer under the marismas made that area particularly vulnerable to overdraft. Hydrogeologists advised the INC to strictly limit water extraction in the marshes, and instead to make use of the land by diverting water from the Guadalquivir River and its tributary streams to rinse the fields of salt and create "very fertile agricultural soil" capable of supporting rice and fodder crops.[25] In the arenas, conversely, the FAO reported that annual recharge from precipitation percolated through the sandy soils at a rate of "more than 300 cubic hectares per year," of which around half could be safely captured by wells in order to support intensive irrigation and municipal development across much of the study area.

The INC moved swiftly to submit a proposal for such development to the central government, and in 1971 the Spanish state declared a "high national interest" in the reclamation of 45,950 hectares in the lower Guadalquivir basin. Adhering to FAO recommendations, the Almonte-Marismas plan, a "General Plan of Colonization of areas irrigable with groundwater from the Almonte-Marismas Aquifers," approved by the state in 1972, would leave the water beneath the marismas largely undisturbed. In the arenas, the National Institute for Agrarian Reform and Development (Instituto Nacional de Reforma y Desarrollo Agrario, or IRYDA), which replaced the INC that year, would drill wells capable of pumping a total of one hundred and forty-five cubic hectares of groundwater per year. That water would irrigate newly conditioned fields planted with strategically selected crops, worked by eager colonists. Outside of the lands that the INC planned to expropriate, transform, and redistribute, private investors advised by state experts would pump an additional fifteen cubic hectares of water from their own wells, applying the water to agriculture, touristic development, and urban use. The total amount extracted from the aquifer system under this plan would keep within the limits of the FAO's water budget, avoiding any risk of declining water tables or saline intrusion.[26] The projected

[25] FAO, "Informe al Gobierno del Estado Español sobre hidrogeología: Estudio hidrogeológico de la cuenca del Guadalquivir" (Rome, 1970), 41–46, 56–60, II/18-1-25/26, IGME; Leblic, "La agricultura en Huelva," 19.

[26] Leblic, "La agricultura en Huelva," 19. IRYDA was created by merging the INC with the Rural Land Concentration Service (Servicio de Concentración Parcelaria y

benefits to the local economy would be dramatic: Huelvan newspapers reported optimistically that the plan would quintuple employment and increase net production by a factor of ten.[27] Local residents celebrated the imminent windfall and eagerly anticipated the state's investment in their region.

The state's decisive action masked the scientific uncertainty upon which the Almonte-Marismas plan was based. Aquifer behavior is immensely complicated, and understanding it requires fine-grained knowledge of the entire system, which includes soil, geological strata, adjacent water bodies, and climatological conditions. Water may enter the aquifer from precipitation percolating through permeable layers on the surface; from "losing streams" that seep into the ground as they flow overhead; or from anthropogenic sources such as irrigation runoff or artificial recharge wells. Recharge rates are irregular across the area of an aquifer, impeded by clay soils and heavy vegetation in some areas and facilitated by sandy surfaces or the presence of streams in others. Discharge, likewise, does not occur uniformly: water flows along subterranean gradients into the sea, other aquifers, or "gaining streams"; rises to the surface under artesian pressure; is taken up and released into the air (transpirated) through plants; or evaporates from wetlands where the surface of the earth dips below the water table, forming groundwater-fed springs or lagoons. The type and density of plant cover, seasonal water levels and temperatures of wetlands, topography, complexities of soil and rock strata, and countless other variables render precise measurements of either recharge or discharge virtually impossible without extensive, long-term study. All water budgets, no matter how carefully calculated, are forged from estimated and extrapolated data that simplifies complex and heterogeneous physical systems.

The tools and data available to the researchers who calculated the initial water budget for the Almonte-Marismas plan were primitive at best. The FAO's research had focused on determining the depth of the water table for the purposes of economically efficient extraction, rather than mapping the relationships between geologic strata, surface vegetation, and adjacent water bodies.[28] Test wells were distributed haphazardly, providing irregular and incomplete information

Ordenación Rural), which had administered the regime's long-standing land-concentration program. "Decreto 3220/1971, por el que se aprueba la estructura orgánica del Instituto Nacional de Reforma y Desarrollo Agrario (IRYDA)," Boletín Oficial del Estado 158, January 8, 1972.

[27] Leblic, "La agricultura en Huelva," 19; J. S. Canales, "A fin de completar otras acciones, urge la puesta en marcha del Plan de Regadíos Almonte-Marismas," *ABC-Sevilla*, April 20, 1974.

[28] Aero Service Limited, "Plan general de exploración de aguas subterráneas en España, Zona No. 1—Huelva, Informe Preliminar" (Madrid, September 15, 1964), 5–6, I/9-2-11/12, IGME.

about the water table and its response to pumping, and data on surface temperatures and humidity were compiled from a variety of unofficial, inconsistent, and often unreliable sources. Across significant areas of the aquifer, permeability and infiltration (key factors in subterranean flow rates) were measured at depths of no greater than two meters. The absence of permanent monitoring wells and long-term data collection, meanwhile, translated into an almost total lack of knowledge about seasonal and periodic variations in the water table both in the immediate vicinity of pumping wells and across the entire aquifer system.[29]

In light of the absence of reliable data, the FAO's reports to the Spanish government strongly suggest that their assessment of the Almonte-Marismas aquifer system's potential was at least as much the product of economic optimism as it was of scientific rigor. Given that volumes of recharge and discharge were "difficult to measure directly and precisely," researchers wrote, they "have been estimated in many cases. Once all available measurements were carefully used, *the hydrogeologists' naturalists' sense has often been relied upon* by applying the experience acquired in previous quantitative studies of similar aquifers" (emphasis added).[30] Based on this "naturalists' sense," their formal report provided staggeringly imprecise figures that could be used to justify a wide range of policy approaches. The stored volume of groundwater across the Guadalquivir basin, for instance, was estimated at between fifteen and thirty billion cubic meters of water, with annual recharge and discharge of anywhere from one to two billion cubic meters.[31] The rate of evapotranspiration through soils and plants, the single largest source of discharge in the Almonte aquifer, was calculated using simple proxy data about temperature and radiation.[32] Despite five years of study with state-of-the-art methods and tools, in other words, the aquifer's workings remained largely unknown, and the FAO's answer to the critical question of how much water could be extracted safely was essentially an informed guess.

[29] Pemberton, "Ground-Water Exploration in Spain," 50; N. V. Grontmij, "Informe sobre la evolución del suelo y las posibilidades de riego en la zona de colonización de las 'Marismas del Guadalquivir'" (INC, August 1967), 7, Proyectos INC signatura provisional 16194, Archivo Central del Ministerio de Agricultura, Pesca, Alimentación y Medio Ambiente (AC-MAPAMA); FAO, "Informe FAO," 43.

[30] FAO, "Informe FAO," 108. Original: "Se ha confiado, a menudo, en el sentido naturalista del hidrogeólogo aplicando la experiencia adquirida en estudios cuantitativos anteriores, de mantos acuíferos similares."

[31] FAO, "Proyecto Piloto," 14.

[32] The FAO employed models designed for use in data-poor contexts, deriving their estimates on the basis of temperature measurements (Thornthwaite and Blaney-Cridoloe methods) and radiation measurements (Turc method). FAO, 11; Nurul Nadrah Aqilah Tukimat, Sobri Harun, and Shamsuddin Shahid, "Comparison of Different Methods in Estimating Potential Evapotranspiration at Muda Irrigation Scheme of Malaysia," 2012, 9.

In its final report, delivered to the Spanish government in 1972, the FAO project leaders repeatedly emphasized the preliminary nature of their knowledge of the Guadalquivir basin and advised that large-scale groundwater extraction should not be undertaken without further study. Among other measures, they urged IRYDA and IGME to establish and maintain a series of monitoring wells that would allow them to calibrate for more detailed and accurate models, providing better data on stored volumes and safe yields.[33] Local scientists would need to exercise "hydrogeological vigilance," carefully monitoring fluctuations in the water table and revising their estimates and recommendations repeatedly as development progressed. Policy makers, in turn, should defer to those estimates in crafting regulations on well locations, spacing, and volumes. "Every time that a private person or a state organism" planned to drill a new well or bore for any purpose, the FAO scientists wrote, state regulations should require consultation with scientific experts and a recalibration of the models, ensuring that management of the groundwater system continued to meet users' needs over the long term.[34]

While adhering scrupulously to the FAO's water budget and recommendations with regard to the placement and volume of each well, the Almonte-Marismas plan failed entirely to reflect these substantive warnings.[35] Opting in favor of rapid economic development at the risk of long-term complications, IRYDA and IGME ignored the suggestion that wells be fitted with meters to track extracted volumes and water table levels, which would have facilitated the collection of data and recalibration of models. Instead, they expressed confidence in their ability to successfully transform the region given that "hydrogeologists now perfectly understand the land's potential," a blatant misrepresentation of the FAO's findings.[36] Also contrary to the FAO's advice, the central government made no move to make groundwater part of the public domain, a legal reform that arid jurisdictions around the world had adopted in order to provide direct state oversight and coherent management of the resource.[37] Instead the government left its 1879 Water Law

[33] "Decreto 2148/1972, por el que se aprueba la primera parte del Plan General de Colonización de las zonas regables con aguas subterráneas de los acuíferos de 'Almonte-Marismas' (Sevilla y Huelva)," Boletín Oficial del Estado 191, August 10, 1972.

[34] FAO, "Proyecto Piloto," 64–73.

[35] "Decreto 735/1971, por el que se dan normas a la explotación de las aguas subterraneas en determinadas zonas de Andalucía y en el que se manifiesta la importancia de los logros alcanzados," Boletín Oficial del Estado 93, April 19, 1971.

[36] Antonio Criller, Izak Risseevw, and Manuel López González, "Proyecto de riego por aspersion de parte de la parcela Las Arenas (Villamanrique de la Condesa), Seville, Proyecto FAO-Guadalquivir" (INC, July 1969), Proyectos INC signatura provisional 17414, Archivo Central del Ministerio de Agricultura, Pesca, Alimentación y Medio Ambiente (AC-MAPAMA); M. L. Dominguez, "El 'Proyecto Guadalquivir,'" *ABC-Sevilla*, March 7, 1968.

[37] FAO, *FAO Seminar Report*, 19.

intact, allowing private landowners to drill wells and extract as much water as they liked, and required only that they self-report basic statistics on their use. In practice, this placed the responsibility for producing knowledge about the aquifer on private citizens with a vested interest in protecting their access to the resource. Combined with the regime's unwavering support for increased economic production, the decision not to directly monitor groundwater use would contribute to aquifer overexploitation across the region and engender new social tensions as the plan got underway.

Conservation and Private Development

At precisely the same time that hydrogeologists focused their attentions on the Guadalquivir basin, members of the nascent international conservation community developed an entirely different vision of the same space. The physical isolation of the marismas and the arenas, several days' ride by boat and horseback from the nearest major population centers, had long protected them from the urban and industrial development that had overrun other wild areas across Europe. The varied habitats, ranging from groundwater-fed lagoons to saltwater marshes to pine forests, housed an incredible diversity of wildlife, and particularly birdlife, which nested, bred, fed, and wintered in the various ecosystems of the river basin. For over a century, the area had attracted hunters and naturalists who returned home with rapturous stories of "untouched wilderness" and unparalleled biodiversity.[38] In the mid-1950s natural scientists identified the basin as one of the largest roadless areas in Western Europe and as the single most significant wetland on the entire Western Mediterranean flyway.[39]

As the "Spanish miracle" took shape, ornithologist José Antonio Valverde spearheaded an unprecedented international effort to protect a portion of the Guadalquivir marshes and forests from the onslaught of urban, industrial, and agricultural development. Fundraising and publicity campaigns that included prominent

[38] Examples of foreign visitors' reports on the area include Lord Lilford, "Notes on the Ornithology of Spain," *Ibis* 7, no. 2 (April 1865): 166–77; Howard Saunders, "A List of the Birds of Southern Spain," *Ibis* 13, no. 1 (January 1871): 54–68; Abel Chapman and Walter J. Buck, *Wild Spain* (London, 1893); Leonard Howard Irby, *The Ornithology of the Straits of Gibraltar* (London, 1895); Harry F. Witherby, "Two Months on the Guadalquivir," *Knowledge: Science Magazine* 22 (1899); William Willoughby Cole Verner, *My Life among the Wild Birds in Spain* (London, 1909); Abel Chapman and Walter J. Buck, *Unexplored Spain* (London, 1910); John Hutton Stenhouse, "Bird Notes from Southern Spain," *Ibis* 63, no. 4 (October 1921): 573–94.

[39] Francisco Bernís, "Sobre la personalidad y la obra del Dr. J. A. Valverde," in *Ornitología y conservación de la naturaleza hoy: Homenaje a Dr. José A. Valverde Gómez*, ed. Francisco Bernís et al. (Madrid, 1975), 1–19; José Antonio Valverde, *Memorias de un biólogo heterodoxo*, vol. 4, *La aventura de Doñana. Cómo crear una reserva* (Madrid, 2004).

northern European conservationists such as Julian Huxley, Guy Mountfort, and Max Nicholson, pressured the Franco regime to protect the site. In 1964, the same year the FAO approved Spain's request for a hydrogeological survey, these efforts culminated in an agreement between the newly formed World Wildlife Fund (WWF) and the Spanish government to set aside just under seven thousand hectares of land on the southwestern edge of the marismas as the Doñana Biological Reserve, named for the Coto de Doñana hunting estate it encompassed.[40]

The international campaign made Doñana the most famous natural space in Spain, and Valverde and his allies used this spotlight to push for greater protections. Environmental conservation was quickly becoming a hallmark of developed European states, among which Spain was eager to be counted.[41] Enlarging the Doñana reserve, Spanish conservationists argued, offered an easy and inexpensive way for the regime to publicly showcase Spain's commitment to the environment. In 1969 Franco declared the creation of a 37,425-hectare national park in the Guadalquivir basin centered around the preexisting reserve (see fig. 2). The founding legislation for Doñana National Park was clearly drafted with an international audience in mind and described the site as "one of the most extraordinary places in Europe, not only with regard to the wealth and variety of its flora and fauna, but also for the role it plays as a refuge or nesting area for the most valuable migratory birds of our continent."[42] Conservationists hailed the

[40] José Antonio Valverde, "Anteproyecto para el establecimiento de la Reserva y Estación Biológica de Doñana" (Seville, 1965), Proyectos de obras y de adquisición de Material, 1965, Estación Biológica de Doñana, Seville. For more on Doñana's significance to environmentalism in Spain and Europe, see José Antonio Valverde, "Doñana y las marismas del Guadalquivir: Su rescate y sus problemas presentes y futuros," in *Ornitología y conservacion de la naturaleza hoy: Homenaje al Dr. José A. Valverde Gómez*, ed. Francisco Bernís (Madrid, 1975); Jesús Casas Grande, "The Milestones That Made Doñana a National Park," in *Doñana: Water and Biosphere*, ed. Francisco García Novo and Cipriano Marin Cabrera (Madrid, 2006), 107–16; González Gordon, "The Decisive Years: The Role of Doñana in the History of Conservation," in *Doñana: Water and Biosphere*, ed. Francisco García Novo and Cipriano Marin Cabrera (Madrid, 2006), 95–99; Lino Camprubí, "La naturaleza no existe: Conservacionismos y relaciones internacionales en Doñana," *Arbor* 192, no. 781 (October 2016).

[41] European environmental movements gained popularity and influence throughout the late 1960s. Their efforts (and those of parallel movements outside of Europe) culminated in a series of significant developments during the early 1970s, including UNESCO's "Man and the Biosphere" program in 1970; France's creation of the world's first ministry of the environment in 1971; the United Nations' publication of *The Limits to Growth* and formation of the UN Environmental Program, both in 1972; the adoption of the European Environmental Action Program in 1973; and the creation of the European Environmental Bureau in 1974.

[42] "Decreto 2412/1969, de creación del Parque Nacional de Doñana," Boletín Oficial del Estado 257, October 27, 1969.

new designation as the "definitive" salvation of "one of the most beautiful places in the world, until very recently in grave danger of destruction."[43]

Such optimism notwithstanding, its designation as a national park did not in and of itself guarantee the continued well-being of Doñana's many ecosystems. Like other environmental regulations passed during the dictatorship, protections for the area lacked enforcement, existing largely on paper and posing little real impediment to development. Indeed, the Spanish state simultaneously pursued three incompatible objectives in the same space: while conservationists celebrated the park's creation, the INC and later IRYDA drilled wells on its northern and western borders pursuant to the Almonte-Marismas plan, and the Ministry of Tourism declared a national interest in coastal development immediately to the south. These plans were so incoherent and poorly coordinated that several IRYDA-operated test plots were inadvertently located inside the park's boundaries, while private developers at the new Matalascañas touristic complex on the coast drilled deep wells directly on its southern edge.[44]

The heavy public and private groundwater use underway in the Almonte-Marismas area was fundamentally at odds with the preservation of Doñana's groundwater-dependent ecosystems. These included a series of small lagoons adjacent to Matalascañas's new wells that had formed where the surface of the land dipped below the water table among a line of coastal dunes. More such lagoons lay along the sixty-kilometer boundary between the marismas and the arenas, in an area known as the Vera-Retuerta ecotone. Their brackish water harbored specialized and extraordinarily rich systems of flora and fauna that relied on the shallow water table for their survival.[45] In dry summers, when precipitation was scarce and streams ran dry, the lagoons provided one of the few reliable water sources in the park. Declines in the water table near these lagoons would inflict permanent and catastrophic harm on the park's wildlife.[46]

The drafters of the Almonte-Marismas plan were fully aware that their actions could have significant impacts on natural ecosystems. Indeed, the reduction or

[43] Juan Infante-Galan, "Doñana, Parque Nacional," *ABC-Sevilla*, November 2, 1969, 17.

[44] "'Sevilla y la baja Andalucía tienen elementos sobrados de atracción turística, a condición de que ustedes pongan los medios para hacerlos realidad,'" *ABC Sevilla*, December 22, 1969; Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen sobre estrategias para el desarrollo socioeconómico sostenible del entorno de Doñana* (Seville, 1992), 20.

[45] FAO, "Informe FAO," 43; FAO, *FAO Seminar Report*, 11.

[46] Antonio Rodríguez Ramírez et al., "Colmatación natural y antrópica de las marismas del Parque Nacional de Doñana: Implicaciones para su manejo y conservación," *Revista Cuaternario y Geomorphología* 19, nos. 3–4 (2005): 37–48; José González Arteaga, *El arroz en las marismas del Guadalquivir: Evolución y problemática actual* (Seville, 2005), 61, 199–206, 209–14.

elimination of natural groundwater discharge has traditionally been a feature, not a bug, of a balanced water budget. In an untapped, unconfined aquifer, the stored volume of water remains roughly constant over time while water slowly percolates into and out of the saturated strata, recharging and discharging equal volumes to the surface. The basic principle of a water budget is that water pumped from wells takes the place of natural discharge: the volumes of recharge and stored water remain constant, while wells capture a volume equal to that which would otherwise leave the aquifer through springs, seeps, or the roots of plants. Pumping wells are, in other words, *intended* to capture water that would otherwise reach natural ecosystems. Wells' ecological impacts accelerate, moreover, when they are located close to surface water sources, which are quickly intersected by their cones of depression. Such was precisely the case with the wells of Matalascañas and the groundwater-fed lagoons.[47]

The Almonte-Marismas plan's water budget was based upon an understanding that natural groundwater discharge via deep-rooted plants, low-lying wetlands, and coastal lagoons constituted "waste." Capturing essentially all of the water that would thus be "lost" through natural discharge and employing that water instead in "useful exploitation," according to the FAO, "constitute[d] a perfectly justified mode of management."[48] Heavy pumping in summer, for instance, would temporarily lower the water table and dry out shallow wetlands, thereby "reduc[ing] the useless losses of shallow and artesian waters to evaporation."[49] As a general principle for siting wells, the FAO advised that "it will always be beneficial to locate the wells close to rivers and streams, or on the terraces that border the marshes," so as to more easily intercept water that would otherwise discharge there.[50] Pumping according to these specifications could cut the volume of "wasted" water by half each year, reducing loss from evapotranspiration from an estimated 140 cubic hectares in 1972 to just seventy once

[47] By the 1980s, as the adverse ecological impacts of heavy groundwater use drew growing opposition from environmentalists, the industry standard for water budgets shifted to incorporate new elements of sustainability. Current best practices limit permissible extraction to the volume that can be pumped without "undesirable consequences," which may encompass economic, social, and/or environmental components. John D. Bredehoeft, Stephen S. Papadopulos, and H. H. Cooper, "Groundwater: The Water-Budget Myth," in *Scientific Basis of Water-Resource Management* (Washington, DC: National Research Council, 1982), 51–57; John Bredehoeft, "Safe Yield and the Water Budget Myth," *Groundwater* 35, no. 6 (1997): 929; William M. Alley, T. E. Reilly, and O. L. Franke, *Sustainability of Ground-Water Resources*, US Geological Survey Circular 1186 (Denver, 1999); John F. Devlin and Marios Sophocleous, "The Persistence of the Water Budget Myth and Its Relationship to Sustainability," *Hydrogeology Journal* 13, no. 4 (August 2005): 549–54.

[48] FAO, "Proyecto Piloto," 17.

[49] FAO, "Informe FAO," 110.

[50] FAO, 45.

the state's work was complete.[51] In short, in keeping with standard water management practices of the era in which it was designed, the plan intentionally diverted water away from groundwater-dependent ecosystems and toward irrigation and tourist development.

The long-standing, widely accepted understandings of the relative value of economic development and the desirability of wetlands reclamation were already coming under scrutiny when the Almonte-Marismas plan was drafted. French geologist Pierre Heurteaux, a member of the FAO team, had warned in 1970 that the wells at Matalascañas were poised not only to draw seawater into the aquifer but to permanently drain the adjacent lagoons, which he described as an undesirable outcome.[52] But Heurteaux's warnings fell on deaf ears at the Ministry of Agriculture, where officials insisted that rather than endangering the park's flora and fauna "the exploitation of this aquifer ordered by the Administration [was] the best guarantee" of Doñana's protection, as the agricultural land would provide a buffer between the park and more intensive industrial or urban development. Without offering any specific proposals, the ministry promised to "adopt the necessary measures to avoid affecting the conservation of the currently existing biotope of the National Park of Doñana by the capture of hydraulic resources in the Almonte Marismas area."[53] No record of any such measures exists. Instead, between 1972 and 1976 IRYDA drilled more than five hundred irrigation wells and conditioned, leveled, and drained soils across the plan area.

This work took place during a decade of social and political upheaval that surrounded Franco's death in 1975. Throughout the 1970s millions of Spaniards campaigned for labor rights, educational reform, women's rights, regional autonomy, and environmental protection, while regime bureaucrats and opposition leaders negotiated a tense compromise for democratic reforms, culminating in the passage of the Constitution of 1978. This constitution dismantled the highly centralized Francoist state, providing a path to regional self-governance that resulted in the division of the country into seventeen Autonomous Communities. Simultaneously, regional and national politicians sought to maintain recent economic gains and to reinforce new democratic institutions through accession to the European Economic Community, achieved in 1986.

[51] FAO, "Proyecto Piloto," 104.

[52] Pierre Heurteaux, "Influences nefastes que risque d'avoir sur l'equilibre écologique du Parc National de Doñana, l'utilisation à des fins agricoles et touristiques des nappes aquifères d'Almonte et des Marismes" (Informe Station Biologique de la Tour du Valat. Centre National des Rêcherches Scientifiques, 1970).

[53] Decreto 2148/1972, por el que se aprueba la primera parte del Plan General de Colonización de las zonas regables con aguas subterráneas de los acuíferos de "Almonte-Marismas" (Seville and Huelva).

Throughout all these changes, and in the face of a growing public interest in conservation and environmental protection, IRYDA resolutely continued work in the Almonte-Marismas area according to its original plan. Responding to both international and domestic pressure, Spanish policy makers professed their commitment to environmental protection and enacted new laws on pollution and resource use, but again they failed to allocate resources or personnel for effective enforcement. Career civil servants who had spent decades dedicated to the pursuit of economic growth viewed the new directives from Madrid and Brussels with skepticism and, at times, outright hostility. With regard to water policy, despite a series of reforms and the adoption of a new Water Law in 1985 practices at every level of Spanish government remained rooted in the hydraulic paradigm that had dominated since the turn of the century, in which water use for economically productive purposes was treated as an absolute good deserving of the state's unmitigated support.[54]

Accordingly, while protections for Doñana improved on paper over the course of the political transition, they did not impede the continued development of groundwater resources. In the late 1970s, having completed the basic irrigation infrastructure for the first sections of the plan area, IRYDA returned most of the newly irrigated lands to their original owners and began the process of installing colonists on the remainder. Those selected were trained and equipped to cultivate diverse crops including fruit trees, industrial plants, fodder, and grains, all of which had proven well-suited to the nutrient-poor soils of the arenas.[55]

Outside of the plan area, landowners carried out a more dramatic transformation using the knowledge, equipment, and infrastructure the state had introduced. IRYDA offered loans for diesel-powered drilling rigs and field preparation, while

[54] On the Spanish environmental movement in the years surrounding the democratic transition and the persistence of productivist and supply-side environmental policies, ideas, and personnel in the post-Franco state, see Susana Aguilar Fernández, "Convergence in Environmental Policy? The Resilience of National Institutional Designs in Spain and Germany," *Journal of Public Policy* 14, no. 1 (March 1994): 42; Millán, *Una tierra abierta*, 278–80; Susana Aguilar Fernández, "Spain: Old Habits Die Hard," *Administration and Society* 34 (2003): 173; José Luis Ramos Gorostiza, "Gestión Ambiental y Política de Conservación de la Naturaleza en la España de Franco," *Historia industrial* 32 (2006): 123; Pablo Corral Broto, "Sobre la sociedad ambiental," April 2012; Sarah R. Hamilton, "Environmental Change and Protest in Franco's Spain, 1939–1975," *Environmental History* 22, no. 2 (2017): 257–81; Sarah R. Hamilton, *Cultivating Nature: Conservation in a Valencian Working Landscape* (Seattle, 2018), 90–100 and 134–37. On the political history of the Spanish transition to democracy more generally, see Gregorio Morán, *El precio de la transición* (Barcelona, 1991); Carme Molinero, ed., *La transición, treinta años después: De la dictadura a la instauración y consolidación de la democracia* (Madrid, 2006); Javier Tusell, *Spain: From Dictatorship to Democracy* (Hoboken, NJ, 2007).

[55] Joan Corominas Masip, "La agricultura en el entorno de Doñana," *Revista de Obras Públicas* (1995), 70.

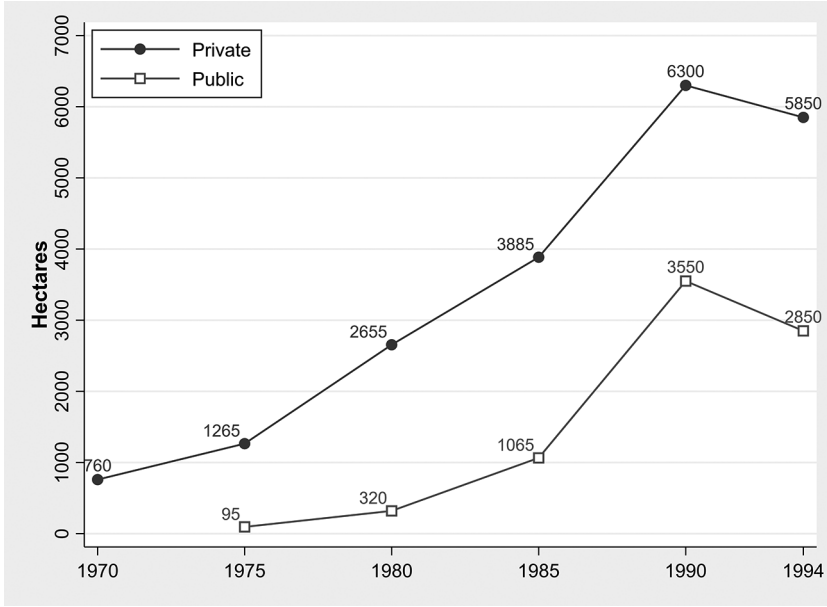

FIG. 4.—Area of public and private land irrigated by groundwater from the Almonte-Marismas aquifer, 1970–94. Market factors such as labor costs and increased competition from non-European producers led to a slight dropoff during the early 1990s, but by 2000 the area of cultivation was again climbing rapidly, driven entirely by private investment. This later period is not shown here due to inconsistencies in available data sources. Data from Corominas Masip, "La agricultura en el entorno de Doñana," 71.

IGME provided free consultations on where and how to drill one's own wells.[56] Encouraged by such support, over the course of the 1970s private spending on groundwater extraction in the Guadalquivir basin significantly outpaced the state's (fig. 4). By the end of the decade private development had given rise to a landscape that bore little resemblance to the small farms and diverse crops originally envisioned by state planners. Just north of the park, a pair of neighboring landowners constructed a thousand hectares of water-intensive rice paddies,

[56] ASAGA, "Fomento de regadíos," *Boletín Informativo de ASAGA*, August 1978, ASAJA-Seville; IRYDA, "Préstamos para puestas en riego," *Boletín Informativo de ASAGA*, August 1981, ASAJA-Seville; IRYDA, "Reglamentación de los créditos para regadíos y modernización de explotaciones," *Boletín Informativo de ASAGA*, March 1982, ASAJA-Seville; ASAGA, "Auxilios del IRYDA a los agricultores y ganaderos," *Boletín Informativo de ASAGA*, June 1982, ASAJA-Seville; Antonio Aguilar Saenz, "El empresario agrícola y las aguas subterráneas," *Boletín Quincenal Informativo de ASAGA*, October 1978, ASAJA-Seville.

flooding their fields with some twenty cubic hectares of groundwater each year. To the west, vast monocultures of fat red strawberries grew on thick beds of imported fertilizers, soil, and plastic that entirely isolated them from the natural substrata (fig. 5). Virtually the entire crop was exported to the European market, where it garnered hefty profits. Huelva's mild climate meant that fruit ripened some forty days earlier than it did in other major production areas, allowing Huelvan farmers to charge up to three times more than they could for fruit sold at the height of the season. With the right inputs of fertilizers and chemicals, a strawberry producer in Huelva could produce some six thousand kilograms of fruit per hectare relying only on precipitation; groundwater irrigation increased that number to thirty thousand. Cultivators in the towns of Moguer and Palos de la Frontera alone, on the western edge of the aquifer, produced thirty-seven million kilograms of strawberries per year, adding around 3.2 billion pesetas to the local economy. Across Huelva, strawberry cultivation directly employed well over half of the rural population and attracted tens of thousands of migrant workers during the three-month harvest season. Infected by the "red fever," colonists in the Almonte-Marismas plan area soon abandoned their state-sanctioned crops for strawberries, taking on heavy debts to purchase the necessary chemical and technical inputs. Wealthier neighbors and foreign investors took advantage of the resulting bankruptcies to purchase lands within the original plan area for their own operations, thereby undoing much of the land redistribution that had motivated the plan in the first place.[57]

In its 1972 report, the FAO had cautioned the Spanish government against permitting the "rapid development, by private initiative," of groundwater in the lands surrounding the plan area. Allowing such development, scientists warned, would impede the state's ability to monitor or control the water, and would

[57] Gómez, "El fresón en la comarca de Moguer," *ABC Sevilla*, August 11, 1968; José Manuel Gómez, "Exposición sobre cultivo del fresón," *ABC Sevilla*, May 15, 1971; José Manuel Gómez y Mendez, "Auge y brillantez en las fiestas del fresón," *ABC Sevilla*, May 9, 1972; Leblic, "La agricultura en Huelva," 19; EFE, "Diez millones de kilos, cosecha de fresas en la comarca de Moguer," *ABC Sevilla*, June 26, 1979; Teresa G. Manrique, "Una agricultura potencialmente rica, en situación de bancarrota," *ABC-Sevilla*, April 14, 1983; Elisa Navas, "Huelva: Casi cuarenta millones de kilos de fresones," *ABC-Sevilla*, June 28, 1985, 44; Eugenio Cosgaya, "Los terrenos para el cultivo de la fresa en Huelva se incrementan en un veinte por ciento," *ABC Sevilla*, February 19, 1989, sec. 57; IARA, "El acuífero Almonte-Marismas," 1990, 9–10, 10319, Archivo Central de la Consejería de Agricultura, Pesca y Desarrollo Rural; Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen*, 16, 19, 34, 65; Corominas Masip, "La agricultura en el entorno de Doñana," 72; Josefina Cruz Villalón, "The Agricultural Development in the Surroundings of Doñana: Spatial and Landscape Changes," in *Doñana: Water and Biosphere*, ed. Francisco García Novo and Cipriano Marin Cabrera (Madrid, 2006), 278; Francisco García Novo and Cipriano Marin Cabrera, eds., *Doñana: Water and Biosphere* (Madrid, 2006), 85, 134.

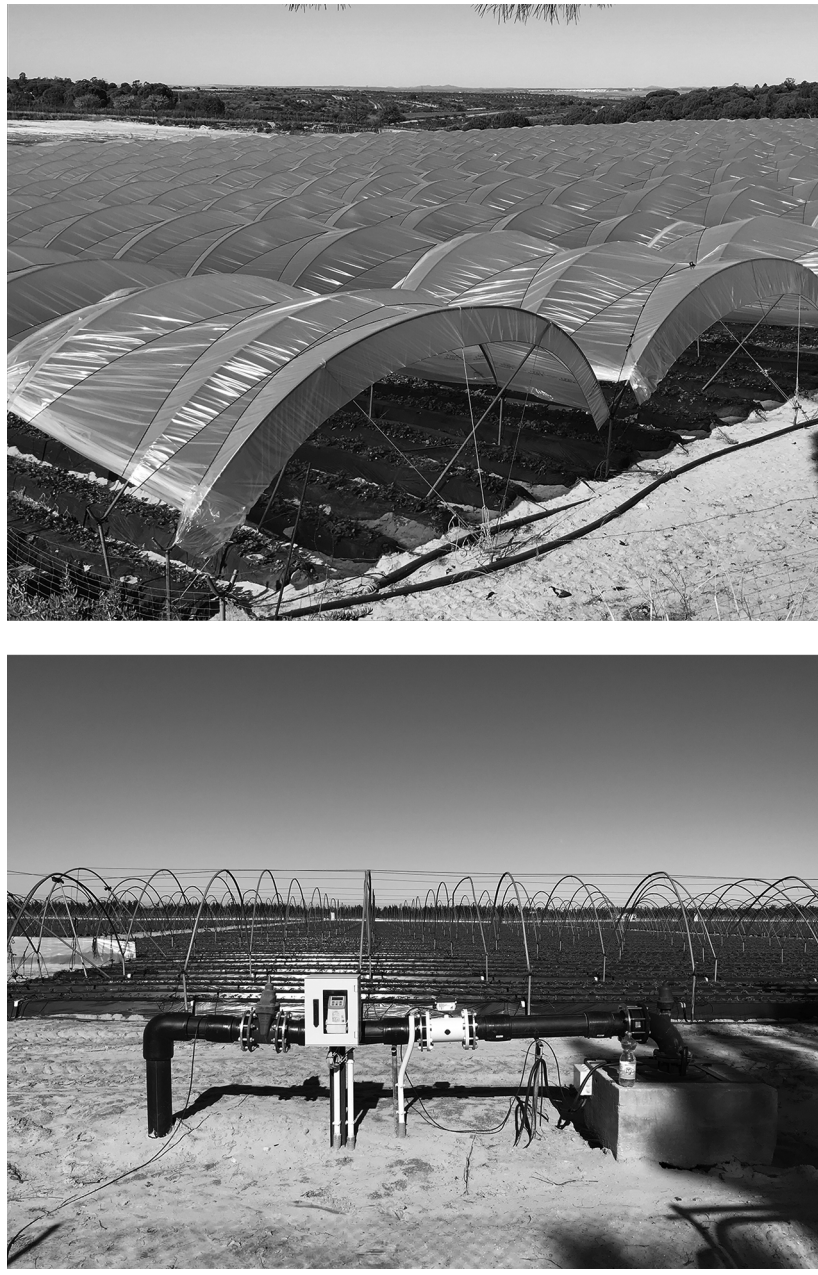

FIG. 5.—Strawberry cultivation near Almonte, 2017. Photos by author. Color version available as an online enhancement.

almost certainly lead to overuse that would reduce the volume available for colonists and permanently damage the aquifer.[58] The Spanish state not only ignored this admonition but in fact actively encouraged and facilitated the spread of unregulated, unmonitored groundwater use, ceding control over the aquifer to private users.[59] In the long run, the Almonte-Marismas plan's most significant impact was not the development carried out by the state itself, but rather its stimulation of private development, accomplished by eliminating technical and fiscal barriers to groundwater use and placing access to the aquifer in the hands of private citizens.

Producing and Wielding Uncertainty

In the face of the state's apparent indifference, natural scientists and conservationists continued to express concerns about groundwater extraction's potential impacts on Doñana and other wetlands across the country. In 1976 Ramón Llamas and Jaime Palop, two of the country's most prominent hydrogeologists, recommended a halt to further public investment in the Almonte-Marismas plan pending a comprehensive assessment of its environmental repercussions.[60] The Ministry of Agriculture's National Conservation Institute (Instituto Nacional de Conservación de la Naturaleza, or ICONA) echoed their warnings and recommended that IRYDA "proceed with caution," improving existing crops rather than "carrying out a massive transformation" as originally planned, which could cause irreparable environmental damage.[61] A 1977 conference on Doñana held in Madrid struck a similar tone, calling for a moratorium on groundwater expansion

[58] FAO, "Proyecto Piloto," 64–73. FAO, 65.

[59] Miren Etxezarreta and Lourdes Viladomiu, "The Restructuring of Spanish Agriculture, and Spain's Accession to the EEC," in *The International Farm Crisis*, ed. David Goodman and Michael Redclift (New York, 1989), 156–82; Robert C. Hine, "Customs Union Enlargement and Adjustment: Spain's Accession to the European Community," *Journal of Common Market Studies* 28, no. 1 (September 1989): 1–27; European Environmental Agency, *Agriculture and the Environment in the EU Accession Countries: Implications of Applying the EU Common Agricultural Policy* (Copenhagen, 2004); Hamilton, *Cultivating Nature*, 149–53.

[60] Ramón Llamas Madurga, "Resumen de los principales intentos de colaboración con los organismos relacionados con la exploitación o estudio de las aguas subterráneas de la zona de Almonte-Marismas o P.N. de Doñana," January 12, 1987, 1, 7065, Archivo General de Andalucía.

[61] ICONA, "Informe: Plan General de Colonización de la Zona Regable Almonte-Marismas (Sevilla-Huelva)," 7, 12–13, 19; Joan Corominas Masip, interview, Seville, November 5, 2017, 6:30–14:45. The Franco regime replaced the Dirección General de Montes, which had been principally dedicated to commercial forestry and wildlife management, with ICONA in 1971. Environmentalists tended to disparage ICONA for its tendency to perpetuate older productivist policies of reforestation and road-building, especially during its first decade. Nonetheless, over its twenty-four-year existence

until the aquifer was better understood.[62] Other interested parties, including scientists at the Doñana Biological Research Station, renowned Sevillian authors Aquilino Duque and José Luís Ortiz Lanzagorta, the WWF, and the National Association of Engineers of Roads, Canals, and Ports called for stronger conservation measures, especially the expansion of Doñana's boundaries to push wells and other development further from the most vulnerable areas.[63] Like the FAO scientists before them, they called for additional research and demanded scientifically sound regulation of existing use, based on carefully monitored and continually updated models of the aquifer.[64] Until it could be proven that groundwater extraction would not cause serious and irreversible environmental harm, they argued, the state should err on the side of caution and restrict further development of the aquifer.[65]

In addition to environmental concerns, evidence of practical and economic problems with the Almonte-Marismas plan mounted throughout the late 1970s. The INC, it turned out, had grossly overestimated the development's economic potential by extrapolating the projected yields of Huelva's reclaimed lands from those of highly successful farms in other parts of the country and submitting record harvest figures as representative averages. Provided with insufficient training and oversight, inexperienced colonists routinely overwatered their fields, overused or underused essential phytosanitary chemicals, and overdrew their financial resources installing capital-intensive strawberry fields. Their failures imposed additional costs on the state, while the damage to the soil wiped out years of reclamation work. By 1975, ICONA analysts concluded from publicly available facts that carrying out the plan as it had been written

ICONA produced a large number of reports that directly critiqued state policies on environmental grounds, especially after it began to hire trained ecologists in 1980.

[62] José Duran Suarez, "I semana de Doñana en Madrid," *ABC-Sevilla*, May 1, 1977.

[63] José Luis Ortiz Lanzagorta, "El factor ecológico," *ABC-Sevilla*, December 26, 1976; Aquilino Duque, "Tanto estorba Doñana?," *ABC-Sevilla*, December 24, 1976; "Pide que la declaración de parque nacional sea extendida a todo el litoral y a fincas contíguas," *ABC-Sevilla*, December 26, 1976.

[64] FAO, "Proyecto Piloto," 71–73.

[65] Conservationists' attitudes toward groundwater use in the Almonte-Marismas region reflect a precautionary approach widely favored by environmentalists, which holds that regulators should limit behavior that may endanger public health or the environment despite a lack of irrefutable proof of a causal link or statistical evidence of harms already caused. Michel Callon, Pierre Lascoumes, and Yannick Barthe, *Acting in an Uncertain World* (Cambridge, MA, 2001), 210; David Magnus, "Risk Management versus the Precautionary Principle: Agnotology as a Strategy in the Debate over Genetically Engineered Organisms," in *Agnotology: The Making and Unmaking of Ignorance*, ed. Robert Proctor and Londa L. Schiebinger (Stanford, CA, 2008), 252.

in 1972 would be a "long and costly project, of dubious future utility when the lands are entrusted to colonists who are not able to cultivate them."[66]

While the economic problems with the plan were obvious to the public, moreover, IGME and IRYDA found that the land itself posed unanticipated physical limitations. IRYDA's discoveries stemmed from practical experience, as their agents repeatedly encountered new obstacles. The marismas, for instance, simply could not be desalinated: no sooner did technicians finish "rinsing" the top layer of soil of its dissolved salts than new salts rose to take their place. In several sectors of the arenas, moreover, water seemed to flow laterally into drawn-down areas much more slowly than expected, and many wells proved unable to pump enough water to irrigate the fields for which they were intended.

IGME identified the scientific explanations for these phenomena, and in so doing discovered that the Almonte-Marismas plan was fundamentally unfeasible. While the agency had ignored many of the FAO's recommendations with regard to ongoing research, it did partially monitor the aquifer through core samples and well registers within the plan area. Data from these sources revealed that the original assessment of the land, upon which the plan had been based, suffered from several critical errors. Artesian pressure under the marismas would always force more saline water to the surface, no matter how assiduously IRYDA "rinsed" the soil. The FAO's hydrogeologists had failed to take into account the presence of a semi-impermeable layer of oxidized sand some two meters below the surface across much of the arenas, which meant that far less water recharged to the aquifer from the surface than they had originally estimated.[67] Once this was taken into account, IGME found that the revised rate of recharge was more than 30 percent lower than the preliminary estimates. On top of this, lateral flow within the aquifer was slower than initial calculations had suggested, such that pumping wells could easily outpace the rate at which water could flow back into their areas of influence. The volume that could be captured without damaging the aquifer, accordingly, was only a fraction of that set forth in the original plan.

IGME incorporated this new information into an updated model in 1982, using a state-of-the-art digital simulation to "permit a quantitative analysis of the

[66] ICONA, "Informe: Plan General de Colonización de la Zona Regable Almonte-Marismas (Sevilla-Huelva)," 7, 11–13.

[67] Leblic, "La agricultura en Huelva," 65, 73; "Decreto 2244/1974, por el que se aprueba la segunda parte del Plan General de Transformación de la zona regable con aguas subterráneas de los acuíferos de 'Almonte-Marismas' (Sevilla y Huelva)," Boletín Oficial del Estado 188, August 7, 1974; ICONA, "Informe: Plan General de Colonización de la Zona Regable Almonte, Marismas (Sevilla-Huelva)," 12; Jesús Casas and Carlos Urdiales, "Introducción a la Gestión Hidraulica de las Marismas del Parque Nacional de Doñana (SO. España)," in *Bases ecológicas para la restauración de humedales en la cuenca mediterránea*, ed. Carlos Montes del Olmo et al. (Seville, 1995), 170; Corominas Masip, "La agricultura en el entorno de Doñana," 69; Joan Corominas Masip, interview, Seville.

long-term behavior of the aquifer in relation to the planned exploitations and the repercussions of that pumping on Doñana National Park."[68] Going far beyond the simple formulae and analog models the FAO had employed, it encompassed observed data on local variations in water table level, permeability, effective porosity, storativity, aquifer depth, recharge, extraction, and evapotranspiration. By modern standards, IGME's two-dimensional model was crude and inaccurate, but it was nonetheless a dramatic improvement over older ones and represented the best available knowledge at the time.[69]

The 1982 model conclusively showed that groundwater extraction had already dramatically impacted the aquifer system as a whole and the groundwater-dependent ecosystems of the park in particular, and that further extraction would soon produce permanent groundwater exhaustion and contamination. Shallow wells were already running dry in the heavily pumped, entirely unregulated rice- and strawberry-growing regions to the north and west of the park, where IGME recorded significant declines in the water table. In some areas, current levels of extraction were projected to draw down the water table by ten to twenty meters over the course of two decades, a depth that was highly likely to draw saltwater into the aquifer and destroy Doñana's groundwater-dependent ecosystems. On state lands, completion of the Almonte-Marismas plan as written would exhaust both irrigation wells and municipal supplies within just four years. Maintaining current rates of groundwater use over the long term, IGME concluded, was "not possible," and if plans for the completion of still more wells were carried out, they would "exhaust the aquifer in this area in the fairly near future." Based upon repeated simulations, IGME researchers found that reestablishing a hydrological balance—limiting pumping to an amount that could be sustained over the long term without serious adverse economic and ecological impacts—would require immediately halting all new development and significantly curtailing existing use.[70]

At no point, however, did either IGME or IRYDA share this information with outside researchers. Instead, throughout the late 1970s and early 1980s both agencies repeatedly denied that their actions had caused or threatened ecological harm and insisted that completion of the Almonte-Marismas plan remained not only possible but even economically desirable. They hid their knowledge, stonewalling requests from conservationists and independent researchers to share the critical 1982 study, their revised models, or their raw data,

[68] IGME, "Actualización de datos hidrogeológicos en los acuíferos de Almonte-Marismas y mioceno de base" (Madrid, December 1982), 1, 35656, IGME.

[69] IGME, "Actualización de datos hidrogeológicos," 13–20.

[70] IGME, "Actualización de datos hidrogeológicos," 30–47; Francisco Javier Rodríguez Arévalo and Manuel Ramón Llamas Madurga, "Evaluación preliminar del impacto de los bombeos de agua subterránea en el ecotono de La Vera-La Retuerta (Parque Nacional de Doñana)," in *El Agua en Andalucía* (II Simposio sobre el Agua en Andalucía, Granada, 1986), 2:423.

and refused to participate in academic or policy seminars and roundtables. Conservationists and scientists concerned about groundwater development's impact on the park had to rely on partial records from a handful of publicly accessible wells, analogous cases of aquifer exploitation elsewhere in Spain, and their own subjective observations of the park's groundwater-dependent lagoons, none of which carried much weight with a public audience that demanded hard scientific evidence that would justify the project's suspension. Effectively IGME and, to a lesser extent, IRYDA prevented the formation of a scientific consensus and then insisted that the project could not be altered on environmental grounds because such a consensus did not exist. Conservationists' lack of access to evidence rendered it virtually impossible for them to establish a clear connection between groundwater use and ecosystem decline.[71]

Even as IRYDA resisted conservationists' calls for reform, however, the physical realities of slow recharge and failing wells forced the agency to adjust its plans. Over the course of the mid- to late 1970s IRYDA established new limits on the volume of water that each well could extract, and it abandoned plans to transform some sectors entirely. Much of the state land excised from the plan became part of Doñana or of a "pre-park" buffer zone separating the park's most valuable and sensitive ecosystems from areas of heavier development. The largest of these property transfers occurred in 1978, when the Spanish government increased the park's area to fifty thousand hectares and added around twenty-five thousand hectares of "pre-park" forests to the north and west, largely in lands previously set aside for groundwater irrigation. As the area slated for economic development diminished, Doñana benefited, giving IRYDA and other irrigation boosters a ready-made culprit on which to blame local landowners' disappointed expectations. In 1979 Ricardo Grande Covián, the head of IRYDA's regional office, described Doñana's new boundaries as evidence of conservationists' "exorbitant concern for the rights of birds and contempt for those of men." Ignoring all the evidence to the contrary, he reiterated his belief in the "incalculable value" that "the treasure of this water" could add to the depressed region, comparing the "fifty thousand days' work" that the existing irrigated areas generated each year to the "million" that would have been created if the area around Doñana had not been closed to development. Responsibility for the lost economic opportunities, he added, should fall squarely on the Doñana Biological Station (a local shorthand for scientists and conservationists

[71] Llamas Madurga, "Resumen de los principales intentos de colaboración con los organismos relacionados con la exploitación o estudio de las aguas subterráneas de la zona de Almonte-Marismas o P.N. de Doñana," January 12, 1987; M. J. Florencio, "Una 'conspiración de silencio' en torno a Doñana es denunciada por los hidrogeólogos," *ABC-Sevilla*, September 18, 1988; M. J. Florencio, "La 'conspiración de silencio' sobre Doñana se extiende a la Comunidad Europea," *ABC-Sevilla*, December 23, 1991.

in general) and its "meddling in the area of agricultural irrigation and spreading its tentacles into the croplands of the pre-park."[72]

Grande Covián's statements were one manifestation of the official blame-shifting that helped entrench rural antipathy to conservation across the region. The 1984 "Royal Decree modifying the [Almonte-Marismas plan] to make it compatible with the conservation of Doñana National Park," which further reduced the area to be irrigated with groundwater, made no mention of IGME's data or IRYDA's experiences and instead attributed the changes to conservation, not only in its title but also in textual references to the need to "assure Doñana's future."[73] Mirroring this language, national and regional newspapers reported that the state had acted "to preserve the National Park" and accordingly that conservation imposed an "important brake on the possibilities of agricultural and economic development for the towns in the area."[74] Such scapegoating went on for years: in 1986, railing against independent scientists' continued objections to irrigation, the head of the Andalusian Institute for Agrarian Reform (Instituo Andalúz de Reforma Agraria, or IARA, a regional agency that replaced IRYDA in 1984 as part of the broader devolution of national authority) insisted that the Almonte-Marismas plan was "a perfect plan, no matter what the geologists say."[75] Rhetoric such as this helped convince the local population that conservation and economic development were incompatible and further disguised the growing body of evidence of the plan's impracticability, which was the true cause of the alterations. The public came to understand groundwater use as a zero-sum game in which they were asked to weigh the relative likelihood and gravity of projected harms to Doñana against the state's assurances regarding the social and economic benefits of irrigation.

The ostensible conflict between conservation and economic development took on broader implications as Andalusian politicians worked to establish the region as a self-governing Autonomous Community pursuant to the Constitution of 1978.[76] Within the context of political decentralization, the resistance

[72] R. Díaz, "Grande Covián: 'Hay que hacer compatible Doñana con el desarrollo de su entorno,'" *ABC-Sevilla*, July 29, 1979.

[73] "Real Decreto 357/1984 por el que se modifica el Plan General de Transformación de la Zona Regable de Almonte-Marismas para hacerlo compatible con la conservación del Parque Nacional de Doñana," Boletín Oficial del Estado 47, February 24, 1984, 5059.

[74] Elisa Navas, "El Plan de Doñana no incluye a la carretera Huelva-Cádiz," *ABC-Sevilla*, February 5, 1986; M. J. Florencio, "El 'nuevo' Plan Almonte-Marismas," *ABC-Sevilla*, February 19, 1984, 6.

[75] Teresa García Manrique, "Preocupación en el IARA por la falta de agua en el Parque de Doñana," *ABC-Sevilla*, June 30, 1986.

[76] Article 151 of the Constitution established a "fast track" to autonomous status for the "historic nationalities" of Catalonia, the Basque Country, and Galicia, which had passed autonomy statutes prior to the Civil War, and a "slow track" for Andalusia and other regions that required a five-year waiting period and the approval of two-thirds of all local

of local residents, politicians, and IARA agents to the repeated expansion of Doñana National Park by the central government can be read as an assertion of rural Andalusian values and priorities against those imposed by an urban Castilian elite. Huelva's former mayor voiced a typical sentiment when he stated in 1975 that environmental concerns were nothing more than "illogical, unreasonable, pretextual arguments" by meddlesome outsiders, designed to derail the region's long-overdue modernization.[77] Andalusian journalist J. S. Canales wrote skeptically of the park's "alleged natural wealth" and called upon his readers to "react, once and for all, to the series of campaigns that, under the auspices of that almost mythological name of Doñana, attempt to halt or impede" local economic growth.[78] Farmers in Seville and Huelva routinely complained of the "absurdity" of environmental restrictions that rendered large areas of land "unusable" in order to protect natural parks and reserves from even the most minor impacts.[79] Sevillian journalist R. Díaz agreed, noting that this "absurdity" was still more shocking given that "Andalusia has such significant problems of unemployment and economic expansion."[80] Some local politicians attempted to thread the needle between local economic interests and the growing national (and international) environmental movement: Huelvan senator José Luís García Palacios, for instance, hedged that "we are absolutely not against Doñana park, but we want to prevent it from harming the interests of an underdeveloped province such as

---

and provincial authorities. In 1980, Andalusia became the first "slow-tracked" region to obtain the status of Autonomous Community. On the evolution of Andalusian nationalism, see Blas Infante, *Ideal Andaluz: Varios estudios acerca del Renacimiento de Andalucía* (Seville, 1915); Isidro Moreno, *Andalucía: Subdesarrollo, clases sociales y regionalismo*, 2nd ed. (Madrid, 1977); Isidro Moreno, "Identidad cultural y dependencia: Orígenes, bases, bloqueos y desarrollo del nacionalismo Andaluz," *Nación Andaluza* 1 (1983): 63–77; Manuel Ruiz Romero, "La emergencia del andalucismo político en el contexto del tardofranquismo a la transición," in *Actas del III Simposio de Historia Actual* (2002), 639–56.

[77] Francisco Amores, "Entrevistas en 4 capitulos: Pedro Rodríguez," *ABC-Sevilla*, December 12, 1975, 27.

[78] J. S. Canales, "Los regadíos del Plan Almonte-Marismas, en peligro," *ABC-Sevilla*, January 18, 1978.

[79] ASAGA, "Ecologistas de calle Sierpes," *Boletín Informativo de ASAGA*, July 1988, ASAJA-Seville. See also ASAGA, "Indignación en la Sierra Norte por la forma de declaración de Parque Natural," *Boletín Informativo de ASAGA*, July 1989, ASAJA-Seville; ASAGA, "Atentado al desarrollo de las zonas rurales," *Boletín Informativo de ASAGA*, July 1989, ASAJA-Seville; ASAGA, "Parques Naturales: La Sierra Norte, a tercera divisón," *Boletín Informativo de ASAGA*, February 1990, ASAJA-Seville; A. S., "Doñana: Los agricultores del Plan Almonte-Marismas acusan a Chaves y a Marín de los últimos atentados," *ABC-Sevilla*, October 12, 1990.

[80] R. Díaz, "La utópicas pretensiones del 'Plan Doñana' podrían reducirse a una ampliación del Parque Nacional," *ABC-Sevilla*, March 4, 1978.

Huelva."[81] The Vice President of Andalusia likewise explained that the continued expansion of irrigation "could harm the water resources of the park, but the [governing board of the park] cannot lean toward harming the social expectations that exist in the area around Doñana."[82]

When Spain bowed to heavy pressure from the EEC in 1985, reforming its 106-year-old water law, rural Andalusians interpreted the change as yet another stumbling block placed on their path to economic development by outsiders.[83] The new law reclassified groundwater as a public resource on a par with surface water, rendering it subject to strict state oversight, and required groundwater users to register their wells with their local Hydrographic Confederations (centrally managed bureaucracies based on geological divisions between large watersheds) in order to gather data about water use and aquifer levels.[84] Like other environmental laws, however, the 1985 Water Law lacked sufficient funding and enforcement and had few immediate impacts on the management of the Almonte-Marismas aquifer. Citing the risks posed by ongoing development projects including but not limited to groundwater exploitation, the International Union for the Conservation of Nature (IUCN) placed Doñana on its Red List of threatened protected areas in 1986, making it the only space in western Europe to receive this ignominious distinction.[85] On the same grounds, Friends of the Earth and the Spanish Federation for Bird Defense denounced the Spanish government to the European Commission, accusing it of failing to comply with its own legislation regarding the park's protection and of violating the European Directive on Wild Birds.[86] The government offered no response or defense, and the Commission threatened to haul Spain before the Tribunal of Justice to answer for its myriad environmental sins.[87]

[81] EFE, "Estudio en el senado del proyecto de ley sobre Doñana," *ABC-Sevilla*, December 16, 1978.

[82] José Cejudo, "Guerra anuncia que pedirá a la Junta un replanteamiento del Plan Almonte-Marismas," *ABC-Sevilla*, December 14, 1986; M. J. Florencio, "Doñana: Luz verde al Plan Almonte-Marismas con la oposición de los ecologistas," *ABC-Sevilla*, November 26, 1986.

[83] "Ley 29/1985, de Aguas," Boletín Oficial del Estado 189, August 8, 1985; Alejandro Nieto, "Necesidad y directrices de una nueva ley de aguas subterráneas," *Boletín de Información del Ministerio de Obras Públicas*, October 1974.

[84] Juan María Fornés Azcoiti, África de la Hera Portillo, and Manuel Ramón Llamas Madurga, "La propiedad de las aguas subterráneas en España: La situación del Registro/Catálogo," *Ingeniería del agua* 12, no. 2 (2005): 128.

[85] M. J. Florencio, "Doñana ingresa en la lista roja internacional de áreas protegidas en peligro," *ABC-Sevilla*, December 12, 1986; A. S., "Doñana: El Gobierno no se pronuncia sobre las denuncias presentadas ante la CEE," *ABC-Sevilla*, December 16, 1986; Florencio, "Doñana: Luz verde al Plan Almonte-Marismas con la oposición de los ecologistas."

[86] EFE, "Denuncian al Gobierno español ante la CEE por incumplir la legislación en Doñana," *ABC-Sevilla*, December 15, 1986.

[87] A. S., "Doñana: El Gobierno no se pronuncia sobre las denuncias presentadas ante la CEE."

By far the most vocal critic of the state's continued work in the Almonte-Marismas area was Dr. Ramón Llamas, president of the International Association of Hydrogeologists, who had dedicated much of his career to studying the relationships between Spain's surface ecosystems and subterranean aquifers. Based on his observations in eastern Castile-La Mancha, where uncontrolled groundwater exploitation had almost entirely destroyed the Tablas de Daimiel wetlands, Llamas had urged developers to exercise caution in the case of Almonte-Marismas since first becoming involved in 1976. For fifteen years, he attempted to establish scientific collaborations with IGME and the successive agencies of the INC, IRYDA, and IARA, all of which ignored or refused his requests to meet with him or to share data. Because he was denied access to IGME's records and monitoring wells, Llamas had no hard evidence that the aquifer was being overexploited or that groundwater use was harming Doñana, and thus had been unsuccessful in his efforts to launch an independent investigation by international experts.[88] Frustrated, he condemned what he described as a "conspiracy of silence" in which IGME had established impenetrable "information barriers" to hide their data from the public and from those who sought to study the aquifer.[89]

The break in Llamas's case came in late 1987, when a sympathetic civil servant provided him with a "pirated" photocopy of IGME's 1982 report showing aquifer declines and damage to the Vera-Retuerta lagoons. Upon Llamas's publication of the data, IGME reluctantly confirmed his findings and went on to report that its latest models predicted the permanent disappearance of groundwater-dependent ecosystems within the park by 2010.[90] While many water users remained deeply skeptical of such claims, within the scientific community this admission generated a broad consensus around three basic facts. First, the Almonte-Marismas aquifer's stored volume had declined since 1970 as a result of large-scale groundwater use. Second, falling water tables had already damaged ecosystems within the park. And third, if groundwater extraction continued at the current rate the aquifer would soon be irreparably damaged, with major impacts on ecosystems within the park and on the viability of existing wells. For years, the park's governing board, local politicians, and the Andalusian press had denounced conservationists' warnings as "baseless" and insisted that more research was needed before taking any actions that could curtail economic growth. Now, as one journalist noted,

[88] M. J. Florencio, "Doñana: Una comisión internacional evaluará los efectos del Plan Almonte-Marismas," *ABC-Sevilla*, April 3, 1988.

[89] Florencio, "Una 'conspiración de silencio' en torno a Doñana."

[90] IGME, "Simulación de La Evolución Piezométrica Del Aquifero Almonte-Marismas: Horizonte Año 2010" (IGME, 1987); Florencio, "Una 'conspiración de silencio' en torno a Doñana"; M. J. Florencio, "Llamas: 'Si el próximo trienio es poco lluvioso, el desastre de Doñana será patente en plena Expo,'" *ABC-Sevilla*, February 4, 1990.

"the situation has changed radically now that IGME finally agrees with some of Llamas's thesis."[91] In the summer of 1988 the park's board ordered IARA to suspend the development of new areas and commissioned experts from the WWF and the IUCN for a comprehensive study of the impacts of development on Doñana.[92] Like Llamas before them, the experts who arrived to carry out this task (including Pierre Heurteaux, the hydrogeologist who had warned of potential environmental damage nearly twenty years earlier) experienced "serious difficulties" in obtaining information from IGME and IARA and condemned the agencies' failure to monitor the aquifer adequately. In their final report they echoed many of Llamas's claims about the damage that had already been done and recommended that groundwater use in and around the plan area be reduced from the original plan's one hundred and sixty cubic hectares of water to about seventy-five cubic hectares per year.[93]

The emergence of a clear scientific consensus and the legal changes governing groundwater use had limited impacts, however, in light of the failure of the Guadalquivir Hydrographic Confederation (Confederación Hidrográfica del Guadalquivir, or CHG) to enforce the new orders. By some estimates more than 80 percent of groundwater users across the national territory failed to register their wells as mandated by the 1985 Water Law, and those who did frequently found that the Confederations' agents had little interest in actually monitoring their water use.[94] Ever since their creation in 1926, the Hydrographic Confederations had been devoted to encouraging economic growth by making water available on demand to anyone who could put it to productive use.[95] The new policies, designed to balance economic development with environmental conservation, were anathema to engineers and bureaucrats who had spent their careers dedicated to supply-side water management and who had been trained to see water evaporating from wetlands or running to the sea as "wasted." Their general resistance to the change was magnified in the case of groundwater, with

[91] Florencio, "Una comisión internacional."

[92] E/P, "La CEE denuncia al Gobierno español por la degradación del Parque de Doñana," *ABC-Sevilla*, August 12, 1988; "Decreto 181/88 de 3 de mayo por el que se aprueba definitivamente el Plan Director Territorial de Coordinación de Doñana y su entorno," Boletín Oficial de la Junta de Andalucia 37, May 13, 1988; IARA, "El acuífero y la zona regable de Almonte-Marismas," 1990, 5, 10319, Archivo Central de la Consejería de Agricultura, Pesca y Desarrollo Rural.

[93] Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen*, 29–30.

[94] Fornés Azcoiti, de la Hera Portillo, and Llamas Madurga, "La propiedad de las aguas subterráneas en España," 128.

[95] Rafael Gasset, *Plan Nacional de Obras Hidráulicas* (Madrid, 1902); Manuel Lorenzo Pardo, *Plan Nacional de Obras Hidráulicas*, vol. 1, *Exposición General* (Madrid, 1933); Alfonso Peña Boeuf, *El Futuro Plan de Obras Públicas del Estado Español* (Burgos, 1939); Swyngedouw, *Liquid Power*, 86–95.

which they had no training or experience and which they tended to view as inexhaustible.[96] Most agents of the CHG, consequently, simply refused to process local irrigators' well registrations. Applications for registrations and for new wells piled up for years, creating an immense backlog that even today—thirty-seven years after the water law's passage—contains thousands of unsettled cases. In the meantime, irrigators simply went on as they had before the law's passage, drilling wells and pumping water however they saw fit with no oversight or monitoring. A frustrated Javier Castroviejo, head of the Doñana Biological Station, described the result as "a chaotic situation" in which irrigators routinely violated water laws that "did not extend out of the offices and into the field."[97]

It was not only legitimate landowners who took advantage of this official neglect. Drawn by the promise of strawberry profits and emboldened by the CHG's lack of vigilance, squatters moved into the public lands of the pre-park, where the state's decommissioned wells peppered the reforested landscape. There, they illegally reopened wells, drilled new ones to augment their water supply, and erected greenhouses among the trees. Their submerged electric pumps were virtually invisible from the surface, and easily transported, diesel-powered rotary-percussion rigs could drill twenty to thirty meters in a single night. One 1,500-hectare area of public forest became known as "Las Malvinas," the Spanish name for the Falkland Islands, when locals capitalized on the distraction afforded by the ten-week Falklands War to transform the entire area into a strawberry plantation. In 1991 park employees acknowledged that illegal cultivation occupied three thousand hectares of protected land, though local environmental groups insisted that the real number was closer to ten thousand. The volume of water extracted from the aquifer continued to increase, though there remained no way to measure precise volumes, and the falling water table had obvious impacts on Doñana's shrinking lagoons (fig. 6).[98]

Pro-development politicians and bureaucrats flatly rejected such conclusions, discounting the evidence of aquifer decline, illegal water use, and ecological deterioration. While attending a strawberry convention at Matalascañas in 1989, for

[96] For another case of a Hydrographic Confederation's failure to protect an aquifer in its jurisdiction from overexploitation, see Hamilton, *Cultivating Nature*, 166–70.

[97] Ted Hollis et al., "The Implications of Groundwater Extraction for the Long-Term Future of the Doñana National Park" (World Wildlife Fund, May 1989), quoted in app. 3.

[98] E. P., "Los alcaldes de la zona advierten que Doñana correrá peligro si no hay desarrollo económico de la comarca," *ABC-Sevilla*, December 18, 1991; IARA and Consejero de Agricultura, Pesca, y Desarrollo Rural, "Documents Related to the Revision of the Almonte-Marismas Plan" (Instituto Andalúz de Reforma Agraria, 199R1), box 10319, Archivo Central de la Consejería de Agricultura, Pesca y Desarrollo Rural; Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen*, 29–32, 82–83; Corominas Masip, "La agricultura en el entorno de Doñana"; Joan Corominas Masip, interview, Seville.

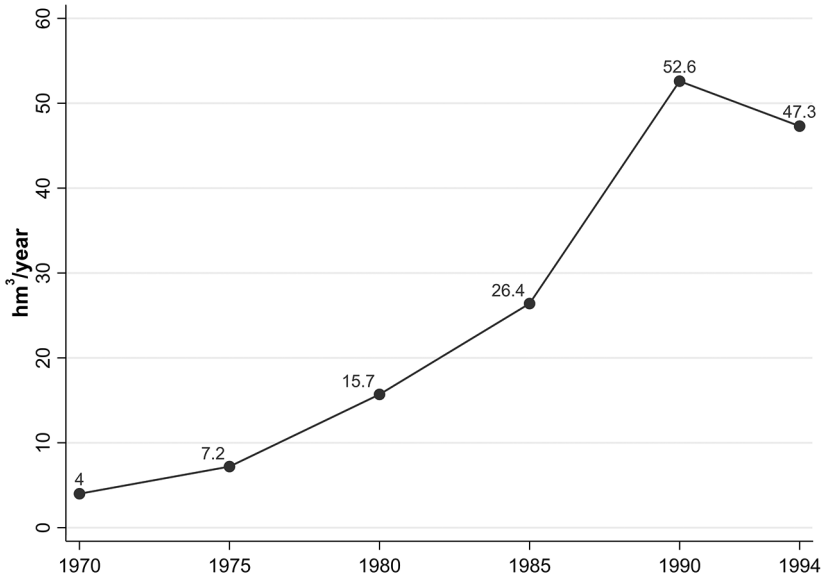

FIG. 6.—Volume of groundwater extracted for irrigation within the Almonte-Marismas plan area, 1970–94. These data do not reflect the volume of water pumped from the aquifer by wells located outside of the plan area, notably those within the area of private strawberry cultivation to the west. The area of that cultivation, and the likely volume of extraction, nearly doubled following a slight decline in the early 1990s. Due to the lack of monitoring on wells that would provide accurate measurements, numbers are approximate. Data from Corominas Masip, "La agricultura en el entorno de Doñana," 71.

instance, the president of Andalusia confidently told reporters that Doñana's aquifer "is not in any danger."[99] His economic minister likewise insisted that "the aquifer is doing very well, the level of the wetland is very high. . . . There is no ecosystem or species at risk of extinction. . . . There is no scientific data that can make one think that Doñana is in danger."[100] When a left-wing politician cited WWF reports in his argument to curtail irrigation, the Andalusian minister of public works contested the figures and insisted that the CHG "rigorously" monitored the aquifer and the wells that drew from it to prevent ecological harm.[101] Such statements were demonstrably untrue. IGME's decade-long effort to prevent the

[99] M. J. Florencio, "Doñana: Veinte puntos que cuestionan la gestión del parque," *ABC-Sevilla*, March 1, 1989, 36.

[100] José Cejudo, "Montaner dice que hay consejeros más representativos que él para el Patronato de Doñana," *ABC-Sevilla*, April 14, 1991.

[101] Manuel Capelo, "Guerra de cifras entre Montaner y Alcaraz sobre las reservas de agua en Doñana," *ABC-Sevilla*, March 2, 1990.

formation of an adverse scientific consensus by suppressing and distorting information had given way, in an era of nominally greater transparency, to outright gaslighting by proponents of continued groundwater use.

Socially and economically, decades of unregulated private development around the aquifer generated a momentum that has proved nearly impossible to slow. Interviewed in 2017, Emilio Vieira, legal counsel for the Seville farmers' association, described the CHG's failure to adequately regulate private groundwater expansion during the 1980s as having "created a monster," generating cultural expectations of free, unlimited groundwater use and producing local economic reliance on unregulated wells.[102] His assessment echoed that of the WWF/IUCN experts who, in 1991, condemned the official "permissiveness or lack of control" that had allowed illegal groundwater extraction to proliferate, predicting that it would be "difficult to correct."[103] Even when a new generation of civil servants took its place at the CHG in the early twenty-first century, agents who sought to regularize management of the aquifer struggled to overcome the inertia and active resistance of a groundwater-dependent economic and social system.

Today, unregulated wells continue to operate across the Almonte-Marismas aquifer system, physically hidden from view in public lands or operating openly but extralegally while their owners' applications for water concessions languish in the CHG. Groundwater-irrigated rice paddies in the marismas consume some twenty cubic hectares of water each year, at least half of which is extracted illegally, creating a vast cone of depression that has destroyed the wetlands in the north of the park.[104] Strawberry production expanded from an area of about 2700 hectares when the international experts' report was released in 1991 to around 5000 hectares just ten years later, where it has roughly stabilized.[105] In total, Huelva supplies one third of all Europe's strawberries, essentially all of which are irrigated with groundwater and an estimated 50 percent of which rely upon illegal wells.[106] The continued lack of regulation and enforcement means that no one knows precisely how much water is being extracted from the aquifer,

[102] Emilio Vieira, interview, Seville, November 15, 2017, 1:52.

[103] Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen*, 66.

[104] Julia Martínez Fernández and Pedro Brufao Curiel, *Aguas limpias, manos limpias: Corrupción e irregularidades en la gestión del agua en España* (2006), 257, n. 31; Emilio Custodio, Marisol Manzano, and Carlos Montes del Olmo, *Las aguas subterráneas en Doñana: Aspectos ecológicos y sociales* (Seville, 2009), 66, 122; "El fiscal pide cuatro años y medio de cárcel para los dueños de una finca de Doñana por riego ilegal," *El Mundo*, September 25, 2017, sec. Andalucia.

[105] Custodio, Manzano, and Montes del Olmo, *Las aguas subterráneas en Doñana*, 128.

[106] Comisión de expertos sobre el desarrollo del entorno de Doñana, *Dictamen*, 14, 19; Custodio, Manzano, and Montes del Olmo, *Las aguas subterráneas en Doñana*, 127; Guido Schmidt et al., "El estado del agua en Doñana: Una evaluación del estado de las aguas y los ecosistemas del espacio protegido" (Madrid, 2017).

but the volume is certainly well over a hundred cubic hectares, divided about evenly between the original plan area and the private lands outside of it. Official efforts to improve this situation have been desultory at best. In 2014 the Andalusian government produced a "Strawberry Plan" that purported to provide a solution to "the problem of the unplanned irrigation and greenhouse expansion that has occurred in recent decades," and in 2019 the CHG closed 77 illegal wells, but as the WWF noted the Strawberry Plan was never effectively implemented and the CHG left over a thousand other illegal wells unmolested.[107]

Meanwhile, the water table has continued to drop. Virtually all of Doñana's groundwater-fed lagoons have vanished, and precipitation that once filled streams and seasonal pools now soaks into the desiccated topsoil. The results have been ecologically devastating, decimating amphibian populations and leading to the local extinctions of dozens of wetland species.[108] The CHG and the Andalusian government nonetheless ignored calls from scientists and conservationists to declare the aquifer overexploited until 2019, repeatedly insisting in legal filings and public documents that the aquifer's condition remained good and did not warrant new limits on extraction.[109] In the summer of 2021 the European Union's Court of Justice found that the state's failure to address the "excessive extractions of groundwater" from the Almonte-Marismas aquifer or to protect the park from harm constituted a violation of Spain's obligations under the EU Water Framework Directive and the Habitats Directive.[110] Local and national authorities are currently considering ways they might correct the situation, including artificially recharging the aquifer by injecting it with water from already-depleted rivers and reservoirs (themselves endangered by ongoing droughts and warming temperatures), but the damage is unlikely ever to be fully reversed. Meanwhile, irrigators continue to pull hidden water from the ground, transforming it into wealth through

[107] Junta de Andalucía, "Plan Especial de Ordenación de Las Zonas de Regadío Ubicadas al Norte de La Corona Forestal de Doñana" (2014); Eva Hernández et al., "Estado del Acuífero de Doñana: Análisis de WWF del estado de la masa de agua subterránea UH 05.51 en el Plan Hidrológico de la Demarcación del Guadalquivir 2009–2015" (Madrid, February 2014); Juanjo Carmona and Teresa Gil, "A Lost Decade: Report on the State of the Doñana Aquifer" (Madrid, July 2020), 2–3.

[108] Schmidt et al., "El estado del agua en Doñana: Una evaluación del estado de las aguas y los ecosistemas del espacio protegido"; Javier Martín-Arroyo, "Drought and Illegal Wells: Why Spain's Doñana National Park Is Drying Up," *El País*, November 4, 2021.

[109] Hernández et al., "Estado del Acuífero de Doñana: Análisis de WWF del estado de la masa de agua subterránea UH 05.51 en el Plan Hidrológico de la Demarcación del Guadalquivir 2009–2015"; Carmona and Gil, "A Lost Decade"; Martín-Arroyo, "Drought and Illegal Wells"; Case C-559/19, European Comission v. Kingdom of Spain, Official Journal of the European Union C 320/5 (Court of Justice of the European Union, 2021).

[110] Case C-559/19, European Comission v. Kingdom of Spain, Official Journal of the European Union.

the cultivation of high-value crops for voracious European markets. In the process, Andalusian groundwater becomes a highly visible global commodity, drained from beneath the sands to feed the appetites of distant consumers.

Conclusions: Groundwater Management as a "Wicked Problem"

Groundwater's invisibility has contributed to its omission from the extensive historiography on water, much of which has focused on water's role in the consolidation of state power. Erik Swyngedouw's excellent analysis of water policy and Spanish modernization, for example, excluded groundwater because it raised ideological and practical issues that differed markedly from those of the state's broader hydraulic practices.[111] Such scholarly choices both reflect and reinforce a perception that groundwater is fundamentally ungovernable, and thus outside of the nation-building projects that have motivated major public works projects on the surface. Several authors have made this claim explicitly. William and Rosemarie Alley have argued that the nearly ubiquitous presence of subterranean water and the imperceptibility of its extraction makes it a "self-service resource accessible to nearly everyone."[112] Writing of the Ogallala Aquifer in the American High Plains, environmental history pioneer John Opie likewise described groundwater use as "intensely localized and small in scale . . . free from distant technological breakdowns, independent of meddlesome collective decision making and complex water regulations."[113]

Indeed, contemporary water use in Spanish aquifers appears to fall largely outside of the state's control. Thousands of unregulated wells draw water from large aquifers across the peninsula and are a source of constant conflict between water users and other stakeholders. The anarchic nature of groundwater use contrasts sharply with the Spanish state's tight control over surface waters, both during and after the Franco dictatorship. But groundwater's current ungovernability was not an inevitable product of its physical characteristics. Rather, it is a direct consequence of value-based decision making by state actors during nearly seven decades of heavy groundwater extraction. Irrigators and developers gained access to the aquifer only after the state assumed the initial costs and risks of hydrogeologic exploration; illegal and extralegal wells proliferated through the complicity and apathy of local functionaries; state financing of rural electrification, low diesel prices,

[111] Erik Swyngedouw, email to author, July 31, 2017; Swyngedouw, *Liquid Power*. Classic studies of the relationships between hydraulic engineering and state power include Karl Wittfogel, *Oriental Despotism: A Comparative Study of Total Power* (New Haven, CT, 1957); Donald Worster, *Rivers of Empire: Water, Aridity, and the Growth of the American West* (Oxford, 1992); David Blackbourn, *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York, 2007).

[112] Alley and Alley, *High and Dry*, 9.

[113] John Opie, *Ogallala: Water for a Dry Land* (Lincoln, NE, 1993), 18.

and international trade agreements made possible the cultivation and sale of strawberries at substantial profits. Perhaps most significantly, state agents' creation and manipulation of scientific knowledge was central to the emergence of environmental policies and practices with profound repercussions on Huelva's ecological and economic systems.

Predictive sciences, especially those dealing with unseen systems, are highly uncertain and therefore vulnerable to manipulation for political and economic purposes. Naomi Oreskes and Erik M. Conway famously described the ways in which a small group of scientists (the "Merchants of Doubt") repeatedly weaponized scientific uncertainty on issues ranging from tobacco use to climate change, calling for more research on the subject in order to forestall regulation and creating a public perception of unsettled science, despite the existence of broad consensus among experts in the field. Such tactics are far from the exclusive domain of the Cold War cadre upon which Oreskes and Conway focused. Indeed, they are virtually ubiquitous in environmental policy making. But as with the Merchants of Doubt, endless calls for "additional research" in pursuit of an impossible standard of certainty ignore the fact that stakeholders hold diametrically opposed worldviews that science alone cannot reconcile, and mask the essentially political nature of the subjects of regulation.[114]

The question of how best to manage an aquifer cannot be answered by science, because it is not a scientific question. It is a "wicked problem," plagued by stakeholders' and policy makers' incomplete, changeable, and contradictory knowledge, in which any decision will have serious and permanent consequences. Within the political context of late twentieth-century Spain, countervailing pressures for development and conservation required policy makers and bureaucrats to balance the magnitude and likelihood of the economic benefits of groundwater use against the magnitude and likelihood of the adverse environmental impacts it could produce. There was no objectively correct answer, no scenario in which groundwater use would have only beneficial economic impacts without environmental repercussions. The role of scientists in the Almonte-Marismas aquifer was to provide policy makers with an assessment of the likely outcomes of various courses of action, such that they could make informed decisions about how to manage the resource. But as Sheila Jasanoff has noted, "data do not speak for

[114] Oreskes and Conway, *Merchants of Doubt*. For examples of the concept in other contexts, see, e.g., David Michaels, "Manufactured Uncertainty: Contested Science and the Protection of the Public's Health and Environment," in *Agnotology: The Making and Unmaking of Ignorance*, ed. Robert Proctor and Londa L. Schiebinger (Stanford, CA, 2008), 90–107; Magnus, "Risk Management versus the Precautionary Principle"; Scott Frickel and Michelle Edwards, "Untangling Ignorance in Environmental Risk Assessment," in *Powerless Science? Science and Politics in a Toxic World*, ed. Soraya Boudia and Nathalie Jas (Oxford, 2014), 215–33; Nathalie Jas, "Chemicals and Environmental History," *Ambix* 61, no. 2 (May 2014): 194–98.

themselves and scientific conclusions are the result of value-laden choices made throughout the scientific process."[115] The creation, analysis, communication or suppression, and application of scientific knowledge in the Almonte-Marismas aquifer by the FAO, IGME, and the INC/IRYDA/IARA throughout the duration of the project reflected personal and institutional prioritization of short-term economic growth over long-term economic and environmental sustainability.

For over twenty years Spain's rural development agencies ignored hydrogeologists' warnings about the potential repercussions of groundwater extraction, failed to collect data that could be used to reduce uncertainty, and withheld or ignored evidence that could compromise their economic agenda. While it has no direct control over private wells, the state made—and continues to make—groundwater use possible in southern Spain. The desiccated lagoons of Doñana were some of the earliest casualties of such unsustainable practices, but the Huelvan case is far from unique. As a combination of rising temperatures and increased demand exacerbate resource conflicts around the world, the growing scarcity of surface water places new pressures on subterranean resources about which much remains unknown.[116] Recognition of the role of state actors in groundwater development undermines deterministic assumptions about its resistance to regulation and underscores the need for historically informed policy making around this increasingly critical resource.

[115] Sarah Mason-Renton et al., "Science for Policy: A Case Study of Scientific Polarization, Values, and the Framing of Risk and Uncertainty," *Risk Analysis* 39, no. 6 (2019): 1231.

[116] Alexandra S. Richey et al., "Uncertainty in Global Groundwater Storage Estimates in a Total Groundwater Stress Framework," *Water Resources Research* 51, no. 7 (July 2015): 5198–5216; Y. Wada et al., "Modeling Global Water Use for the 21st Century: The Water Futures and Solutions (WFaS) Initiative and Its Approaches," *Geoscientific Model Development* 9, no. 1 (January 21, 2016): 175–222.