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Salt of the Earth

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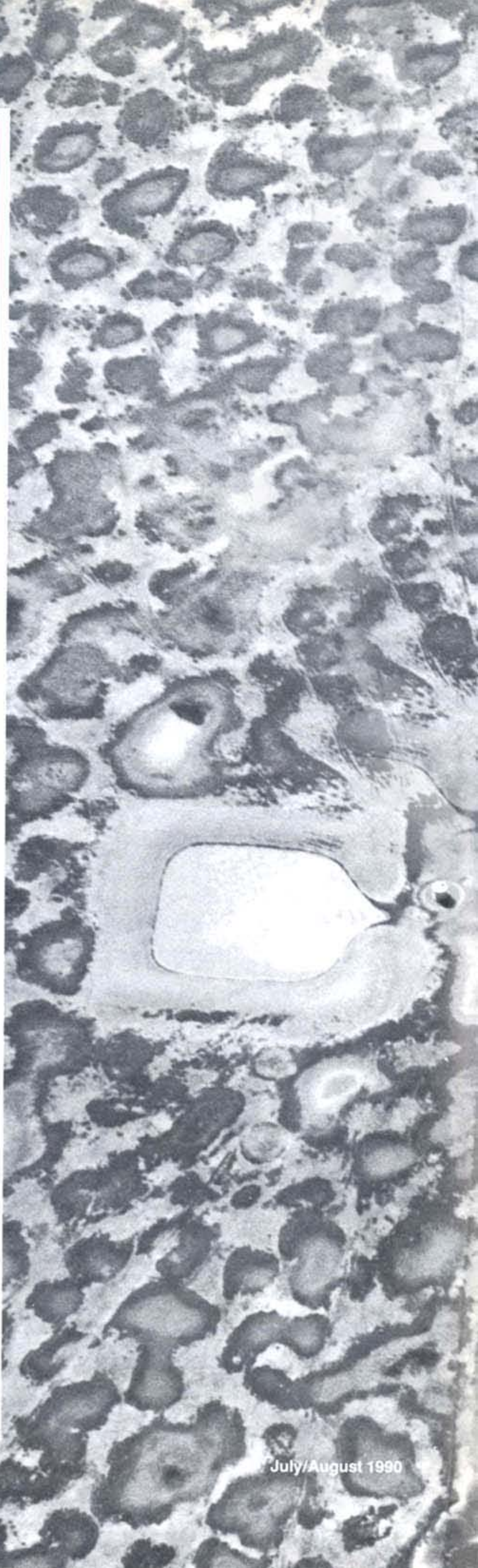

SALT of the EARTH

Secondary Soil Salinization in the Australian Wheat Belt

By Arthur J. Conacher

Thirty-nine percent of the 13,400 farmers throughout southwestern Australia have reported that their land suffers from secondary soil salinization.[1] Last year in that region, 440,000 hectares of land once used as cropland or pasture were determined to be salt affected. That number indicates an increase in salinized land of 500 percent since the first saltland survey was conducted in 1955.[2] Virtually all of this secondary soil salinity is found in the rainfed wheat belt of the state of Western Australia, where some 13 million hectares of the indigenous woodland have been cleared, mostly during this century, to establish a mixed agricultural economy of cereal crops and sheepfarming. The map in Figure 1 on page 6 shows the extent of secondary soil salinization in southwest Australia.

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Stock dams for watering sheep lie amid salt-ravaged fields near Wagin in southwest Australia. (Photo: Comstock—Georg Gerster)

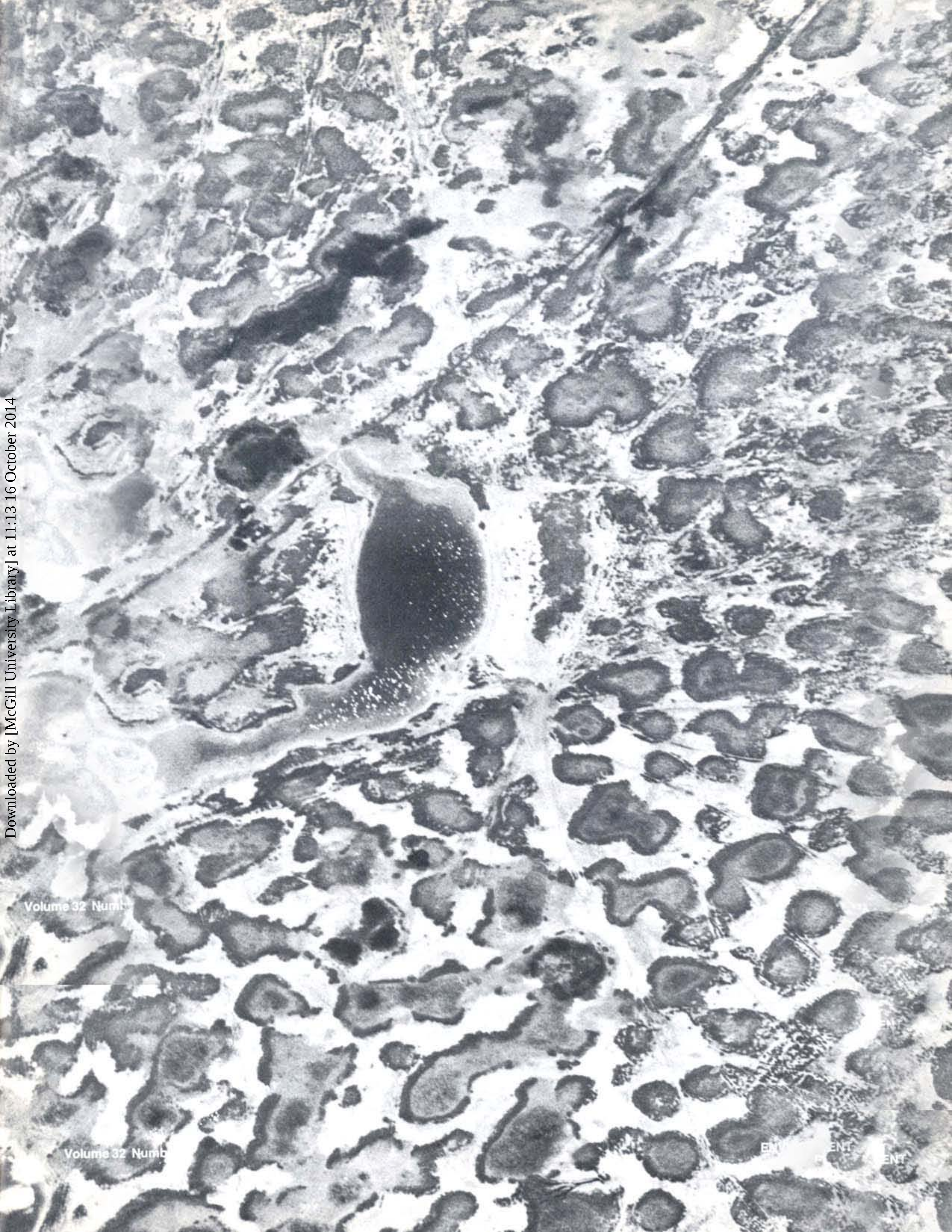
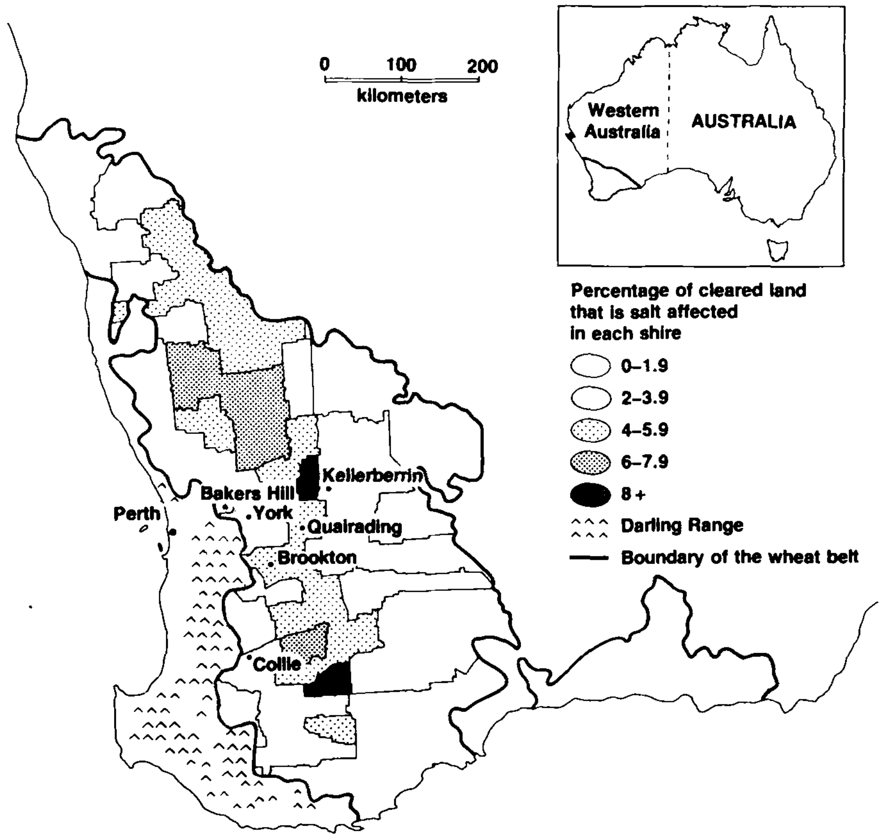


FIGURE 1. Salt-affected lands in the Western Australian wheat belt.



Note: The eastern part of the wheat belt receives a mean annual rainfall of fewer than 300 millimeters and has been cleared for agriculture relatively recently, so the eastern shires generally have less secondary soil salinization than do the western shires, which receive more than 500 millimeters of rainfall annually and have long been cleared for farmland.

SOURCE: Guy Foster, Department of Geography, University of Western Australia.

The proportions of the various salts found in the soil are the same as those in seawater; about 70 percent of the salts are sodium chloride. That similarity reflects the salts' origins in seawater that has been transported inland in the atmosphere and deposited with rainfall.[3] The salts have accumulated, presumably for thousands of years, in both the groundwater and the deeply weathered soils that characterize this ancient landscape. The transformation from natural vegetation to agriculture has disturbed the soils and the hydrologic cycle and has redistributed these salts closer to the soil surface. The precise mechanisms of this redistribution have been the subject of considerable dispute, but it is clear that salinization and disturbance of other soil properties threaten the wheat yield that is so important to the Australian economy.

Not only soils are salt-affected; the water in virtually all of the wheat-belt streams has become too salty for human consumption, and many of the low-lying freshwater lakes have become salty. Water for human consumption now has to be piped to farms and towns from two dams in the forested Darling Range to the west. Clearly, there is far too much salt in this environment, yet, as recently as 1970, agricultural advisers were denying that salinity was a major problem.

Now that the problem is recognized, however, disagreement over the causal mechanisms has given rise to disagreement over the necessary remedial measures. Although many farmers, Department of Agriculture personnel, scientists, and politicians have been involved and considerable funds have been expended, farm advisers still cannot always tell farmers exactly what to do to solve their salinity problems.

The argument now has extended beyond salinity because salt is only one manifestation of a seriously disrupted ecosystem. Other manifestations of disruption, such as waterlogging, accelerated erosion by wind and water, soil structure deterioration, and soil acidification, probably are affecting much larger areas of farmland than are affected by secondary soil salinity, with even more serious consequences.

Early Explanations and Advice

For many years, the advice given by officers of the state's Department of Agriculture to farmers who observed increasing salinization of their land was to fence off the affected land and establish salt-tolerant plants on it. The fencing was recommended to control grazing, and the salt-tolerant plants—although they reduce wind and water erosion, improve the aesthetics of the area, and provide some fodder for stock—essentially were a way to live with the problem instead of solving it. Neither fencing nor salt-tolerant plants could return the land to its original fertility or alleviate salinization. Above all, this approach did nothing to tackle the causes of the problem.

Some people argued that successful establishment of plants on salt-affected land would cause sufficient transpiration to lower the water table and hence, they thought, solve the problem. But this advice was based on the assumption that the predominant underlying cause of salinization is a rising water table. The water table was assumed to be rising because the shallow-rooted agricultural annuals that have replaced the deep-rooted, perennial natural vegetation absorb less water, and the excess water infiltrates the saline groundwater aquifers underlying most of the deep-weathered wheat-belt soils and raises the groundwater table either until it intersects the surface—producing saline seeps that also pollute streams—or until it lies within about two meters of the soil surface. In the latter case, water drawn by suction and capillary action to the soil surface would evaporate and leave the soluble salts behind. During Western Australia's long, hot summers, the salts would become progressively concentrated, leading to plant death.

This very logical explanation has been accepted at least since the publication in 1924 of a widely quoted paper by the engineer W. E. Wood, who, in fact, provided a rather more complex story.[4] In 1962, S. T. Smith, then a part-time student at the University of Western Australia, wrote in his master's thesis that "it is quite certain that land development has resulted in a very much accelerated rise in watertables which, in some cases, have risen from 80 feet to within 6 feet of the surface within 10–15 years of initial clearing."[5] A detailed search through the thesis reveals no evidence to support this assertion. Smith, however, became the state's commissioner of soil conservation in the Department of Agriculture, and various versions of his statement appeared in departmental technical bulletins as well as in other literature.[6] However, it was not until 1979 that detailed evidence was published that supported the rising groundwater table hypothesis of soil salinization.[7]

Root growth in the wheat belt is hampered not only by soil salinization but also by soil compaction caused by heavy farm machinery.

The Whittington Story

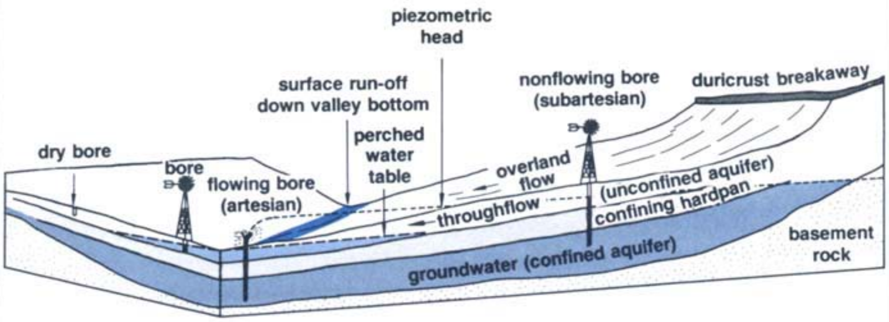
Rising groundwater tables are not the sole explanation of secondary soil salinization in the Western Australian wheat belt. In the late 1940s and early 1950s, Harry Whittington, a wheat-belt farmer, noticed increasing salinization as well as severe gully erosion on his property, Springhill, near Brookton. Although he followed the Department of Agriculture's standard recommendations, he was not satisfied with the results. Whittington's extensive observations of the changed flow regime of a stream running through his property, the water levels in several of his wells, and the results of hand drilling throughout his farm had convinced him that rising groundwater tables alone were not responsible for his problems.[8]

Whittington contacted the U.S. Department of Agriculture for assistance and proceeded to implement their recommendation, which was to construct interceptor banks on the contour, with the first one located as close as possible to the top of the hill and subsequent banks located at intervals down the slope. These banks would intercept overland (surface) flow and, especially, the lateral flow of subsurface water called "throughflow" and, thus, prevent waterlogging further downhill. The underlying reasoning was that secondary salinity is primarily caused by waterlogging, which results from a perched water table in the valley floor, supplied by both throughflow and overland flow (see Figure 2 on page 8).

The Western Australia Department of Agriculture was strongly opposed to Whittington's plan and argued that interceptor banks along the contour would only increase the infiltration of water to the deep aquifer and, therefore, exacerbate the problem. However, Whittington worked steadily to build banks and even sold a portion of his farm to finance their construction. The early results were sufficiently encouraging for Whittington to proceed using borrowed funds. By the early 1970s, water movement over most of his property was controlled by interceptor banks, and he was claiming significant success: Of his original 60.7 hectares of salt-affected land, 56.7 had been rehabilitated and were growing crops; the severe gully erosion had been stopped; and fertilizer applications had been halved because the fertilizer was no longer being washed off the slopes. Whittington said that the increased productivity of the entire property had more than paid for the cost of the program.[9]

Not surprisingly, some of Whittington's neighbors in the Brookton area were sufficiently impressed with his results to implement their own interceptor programs, and, by 1978, 18 farmers in the Brookton area and elsewhere in the wheat belt had constructed interceptor systems despite the continuing hostility of the Department of Agriculture. Whittington was seen by many as the archetypal "Aussie battler," the small man struggling against great odds—in this case, against both nature and bureaucracy. Although he was the

FIGURE 2. Water pathways transporting soluble salts in the wheat belt of Western Australia.



Note: Saline, regional groundwaters beneath the confining hardpan are under pressure and leak salty water to near-surface locations through old root channels and other macropores. Throughflow, which accounts for the greater proportion of water moving in the landscape, is relatively fresh. However, the rising saline groundwaters mix with throughflow, which then spreads the mixture downhill. The salty water accumulates in aquifers perched on top of impermeable hardpans in valley floors. Surface run-off then spreads the salts farther down the valley. Thus, farmers and others may be affected by salinity problems originating in distant watersheds.

SOURCE: Guy Foster, Department of Geography, University of Western Australia.

"salt of the Earth" in the eyes of many, he was certainly "too much of a good thing" in the eyes of the Department of Agriculture.

In 1978, a group of farmers in the Quairading area formed the Whittington Interceptor Salt Affected Land Treatment Society (WISALTS) to promote Whittington's methods. By 1980, the society had attracted more than 1,000 members—nearly one-third of all farmers who were reporting a salt problem on their land at that time. Whittington, now retired, was not a member of the organizing committee, but he was held in very high regard by the society's members and was primarily responsible for training the society's surveyors. These surveyors are hired by farmers to plan and supervise the construction of interceptor systems. The surveyors are themselves farmers who, despite being paid for their WISALTS work, generally lose money because of their extended absences from their own properties. Interceptors have been constructed not only throughout the Western Australian wheat belt, but also on Kangaroo Island in South Australia, near Swan Hill in Victoria, and, very recently, in New South Wales.

The society's influence has been considerable. Although Australian politics is dominated by the Liberal (conservative) and Labor parties, a third party traditionally has represented rural interests. Previously called the Country Party, it was renamed the National Party in an unsuccessful attempt to broaden its electoral base. Several Australian states, as well as the federal government, have been ruled by a coalition of the Liberal and National parties. Presently, in the Legislative Council, Western Australia's upper house of Parliament, a rural voter has as much as 11 times the voting power of an urban voter because of the electoral system.

The antagonism between WISALTS and the Department of Agriculture quickly spilled over into the political sphere as WISALTS farmers let their representatives know their views of the department. As far as department officials were concerned, WISALTS was wrong in encouraging farmers to spend considerable sums of money on an approach that, they said, not only did not work but would actually exacerbate salinization. In fact, the majority of farmers with salt-affected land have not joined WISALTS because they are unconvinced of the benefits of the interceptor method—not because they are happy with the department's advice to abandon land that has become salt affected.

Salinization Research

In 1969, scientists at the University of Western Australia (including the author) began to research the processes responsible for secondary soil salinization in the Western Australian wheat belt. Interviews with farmers revealed little evidence to support the rising groundwater table explanation for soil salinization, whereas field research indicated that throughflow is the dominant mechanism transporting water and, by implication, salts to the low-lying, waterlogged, salt-affected areas called salt scalds.[10] Groundwater aquifers beneath wheat-belt valleys often are under pressure, being confined below siliceous hardpans or other confining, weathered materials. But field drilling by Department of Agriculture personnel has identified a number of places where the hydraulic head of the aquifer lies well below the capillary depth under salt scalds. In some instances, there is no regional aquifer at all. Thus, the presence of a regional aquifer cannot be necessary for salt scalds to form.[11]

Later work investigated the success of the WISALTS approach. Sixteen of the 18 farmers who first implemented Whittington's interceptor method, which became widely known as "Harry Banks," were interviewed in 1977 and 1981, and 28 more WISALTS farmers in Kellerberrin Shire were interviewed in 1981. The interviews revealed that, while results generally had been beneficial, they had not been as good as would have been expected were throughflow the sole mechanism responsible for secondary salinization.[12] Moreover, a detailed, hydrologic investigation of one WISALTS farm showed that both throughflow and deeper groundwater were contributing water and salts to the salt-affected area, with throughflow providing most of the water and the deeper aquifer most of the salts. Thus, any groundwater control measure that does not also control throughflow and, hence, waterlogging of low-lying areas will be insufficient; measures to control both mechanisms must be implemented to prevent salinization.[13]

In the 1970s, scientists of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) also began research into salinity problems, but they focused more on the wetter areas to the west of the wheat belt. There, they found serious land-use conflicts among such activities as bauxite mining, commercial timber production, water-catchment protection, flora and fauna conservation, agriculture, quarrying, road building, construction of power lines, and expansion of the residential areas surrounding Perth. The clear potential for water salinization following forest removal, whether intentional or accidental (for example, from insect attacks caused by habitat disruption), led to a massive research effort on the part of CSIRO, the Public Works Department (which was responsible for water resources), the Forests Department, and the Department of Lands and Surveys. Millions of dollars have been spent setting up and monitoring several experimental sites in the forested Darling Range, including important paired catchment experiments in the Collie River basin and on CSIRO's experimental farm, Yalanbee, about 65 kilometers east of Perth.

Indeed, the first evidence supporting the rising groundwater table explanation of salinization came from one of the Yalanbee sites,[14] but the mechanism was not as simple as many had thought. The groundwater table rose after clearing of the catchment, and stream salinity increased sharply as the groundwater table intersected the interface between the sandy surface soils and the relatively high clay-content subsoils about 0.5 meters below the surface. The saline groundwater mixed with the fresh, ephemeral throughflow, which delivered diluted, but still saline, water to the stream.

The work in the Collie River basin catchment also revealed at least two subsurface aquifers at work: the deeper, saline aquifers, and the shallow, perched, and relatively fresh throughflow. The throughflow was shown to be both ephemeral and seasonal and responsible for transporting most of the water in the landscape. In contrast, the deeper aquifer accounted for only about 10 percent of the water but as much as 90 percent of the soluble salts. Thus, a general explanation of secondary soil salinization requires recourse to both mechanisms. Overland flow also is a potential contributor of water; in many parts of the wheat belt, stream flow from higher elevations brings significant inputs of both water and salts to the salt-affected areas. Consequently, these mechanisms also have to be included in a general explanation.[15] The relative proportions of water and salts being contributed by the different mechanisms may vary markedly from place to place and over time, so each site must be investigated before remedial measures are attempted.

At Yalanbee, CSIRO researchers also investigated another site along Crocodile Creek where the flat valley floor became progressively salt affected. To solve the problem, a 2-meter-deep drain was constructed in the shape of a Y. The stem of the Y was blasted through a rock bar that was obstructing the downhill drainage of groundwater in the deep, saprolite aquifer. The rock bar was forcing water to the surface and causing saline seepages and waterlogging. (Piezometric heads of the groundwater were at least 2 meters above the ground surface in the lowest parts of the valley floor.) The two points of the Y drain pointed uphill. However, the drain did not succeed in removing water from the salt-affected area. Although the hydraulic head was lowered significantly in piezometers located immediately adjacent to the drain, it still remained above the ground surface, which continued to be waterlogged with saline water. The problem beside Crocodile Creek is that the kaolinized materials in the deep-weathered saprolite have very low hydraulic conductivities, ranging from 0.001 to 10 centimeters per day, with a median value on the order of 1 centimeter per day.[16] Such low conductivities permit upward movement of groundwater under hydraulic pressure at rates that are

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A bulldozer digs "Harry Banks" to intercept throughflow and, thus, deter waterlogging and salinization of the valley floor.

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some 10 times lower than the evaporation rate at the site. Thus, although the reason for the failure of the drain was clear, the cause of the continued waterlogging was puzzling because evaporation should have kept the surface dry.

CSIRO researchers invoked three possible mechanisms to explain the continued waterlogging of the site. First, there might be a deeper and less weathered zone below the kaolinized saprolite with a much higher hydraulic conductivity than the kaolinized (pallid) zone. This deeper zone would make it possible for large quantities of groundwater to be imported to the site. The second explanation, which is related to the first, was that water is being forced to the surface under the positive hydraulic head through macropore channels, which occur mainly in the form of old root channels. Both of these explanations subsequently have been shown to be valid elsewhere in the wheat belt.

The third explanation was the throughflow mechanism. CSIRO researchers tested this possibility at Crocodile Creek by excavating a 2-meter-deep ditch at the uphill margin of the main salt-affected area. A strip of land about 30 meters wide below the ditch became relatively dry, and a crop was planted there with some success, but the overall impact of the ditch on the main salt-affected area was minimal. This finding was similar to that obtained later by Department of Agriculture personnel working further to the east and south of Yalanbee where the wheat belt is somewhat drier.[17] Some of the department's work involved the installation of piezometer networks at a number of sites, while other department personnel continued research into the establishment of salt-tolerant plants on salt-affected land.[18] Deep drainage was investigated further and was found to be far too costly for most wheat-belt farmers to implement even where it is technically feasible.[19]

Richard George began a detailed program of research in the 1980s, first through the Department of Geography at the University of Western Australia and then through the Department of Agriculture. George started with a very intensive field study of a small, 12-hectare catchment that was instrumented to measure stream flow, groundwater movement, throughflow, and the degree of soil saturation, but he later studied additional catchments of up to several hundred hectares.[20] Following the work of CSIRO,[21] George also experimented with rows of eucalyptus trees planted uphill from small, saline seeps supplied with water from perennial or seasonal throughflow in the deep, aeolian sands on the hillsides. Planting these trees should increase transpiration and, so, "pump" excess water from the soil. He also tried water harvesting from similar sites as well as groundwater pumping from regional aquifers.[22] The results of this work, currently in various stages of preparation for publication, have been most encouraging.

The Picture for the 1990s

One of the more important changes that have taken place is that many farmers, including many who belong to the WISALTS group, have realized that secondary soil salinization is only one manifestation of an ecosystem that has been severely disrupted by the replacement of natural vegetation with crops and pasture. Such replacement disturbs the terrestrial portion of the hydrologic cycle and the pattern of groundwater movements in particular.

Other disturbances have affected a wide range of soil properties other than salt concentrations and have further threatened the very basis on which Australian agriculture depends.[23] For example, the organic content of wheat-belt soils has decreased, and the soil structure has suffered not only from repeated pulverization by ploughing at excessive speeds but also from a decline in soil biota numbers and activity. Subsoil hardpans have been created by the use of increasingly heavy machinery, as well as by stock trampling. These hardpans have adversely affected root de-

velopment. Soil acidity appears to have increased on a fairly large scale, with the older agricultural areas being affected the most. At pH levels below 5, wheat yields may be low, molybdenum may become unavailable to plants, and other trace elements may be concentrated to toxic levels. Increased surface water repellence is another wheat-belt problem, and it contributes to accelerated soil erosion. The immediate cause of water repellence is an organic film around individual sand grains in the soil and the subterranean clovers used in the pasture phase of the wheat/sheep field-use rotation commonly used by area farmers. These clovers appear to contribute to water repellence as well as to soil acidity, but the causal relationships are not fully understood.

Accelerated water erosion and waterlogging are regarded by the Department of Agriculture as the wheat belt's third biggest problem; wind erosion is the greatest cause of damage, and salinization ranks second. In 1983, the director of the Western Australian Department of Agriculture, E. N. Fitzpatrick, estimated that wind erosion was responsible each year for $38-million

In southwestern Australia, scientists inspect soil salinization that is rapidly extending uphill into a farmer's paddock.

worth of production losses in the wheat belt; $26 million was lost because of secondary salinization; $19 million was lost because of water erosion and waterlogging; and $11 million was lost because of the deterioration of soil structure.[24] Other problems not costed include off-farm effects such as the salinization of water supplies, eutrophication of water bodies, stream and dam sedimentation, and a wide range of adverse impacts on the environment and public health caused by the dramatically increased use of pesticides and herbicides.[25]

The realization that salinity is only one of many facets of land degradation led to two important developments in the early 1980s. One was the formation of the Land Management Society (LMS), of which several WISALTS farmers, including Harry Whittington, were prominent members. LMS differs from WISALTS in that it focuses on the whole range of land degradation problems in agricultural areas—not just salinization—and it explicitly includes Department of Agriculture personnel in its membership and committee structure. Despite this very encouraging development, however, WISALTS continues to operate, and the membership of LMS remains disappointingly small.

The second development was the formation of Soil Conservation Districts in 1982. Farmers in a district who are experiencing a common problem work together with the Department of Agriculture and local government (shire) officials to tackle that problem. The districts and their committees are supposed to be controlled by farmers, with department personnel acting as advisers. The most common problems identified thus far have been vegetation degradation in pastoral areas and, in the wheat belt, secondary salinization, waterlogging, erosion, flooding, and soil structure deterioration. Although the Soil Conservation District approach was not initiated in Western Australia (it appears to have been used first in New South Wales and Victoria in the 1960s), it has been adopted with wholehearted enthusiasm in the western state. In 1989, Graeme Robertson, the Western Australian Commissioner for Soil Conservation, reported that more than 70 percent of land users—including pastoralists in the natural rangelands—were involved in more than 100 districts covering approximately 75 percent of the agricultural land and 80 percent of the pastoral areas of Western Australia.[26]

Clearly, the broad recognition of land degradation problems and the cooperative approach of both LMS and the Soil Conservation Districts are to be applauded. Moreover, because Whittington and WISALTS were the forerunners of these developments, perhaps their achievements will be more widely appreciated. Some problems remain, however. In 1985, Robertson said that the department had reached the limit of its resources, yet only 55 Soil Conservation Districts were either operational or being formed at that date.[27] How well has the department managed a virtual doubling of its responsibiliites in that area in only five years? Also, some farmers have expressed reservations in that they perceive the department as dictating to them through the Soil Conservation District committees. If true, this situation is not only contrary to the intent of the concept but potentially even counterproductive.

The participating farmers' most important reservation is whether the knowledge exists to solve the identified problems. It is not often possible for an adviser to walk onto a farmer's property and tell that farmer exactly how to solve the salinity problem or one of the other manifestations of soil degradation. Moreover, farmers wishing to reduce or avoid altogether the use of synthetic farm chemicals, such as fertilizers and pesticides, receive no assistance from the Department of Agriculture.

Another problem lies in a rather crucial division of responsibilities between government agencies. The Department of Agriculture, although it experiments with trees for salinity control and windbreaks in certain areas, emphasizes the adoption of minimum tillage practices to control soil erosion and improve soil properties. On the other hand, the old Forests Department—now incorporated within the Department of Conservation and Land Management (CALM)—primarily is interested in trees for the production of timber and wood chips and not as a crop producing stock fodder, fruit, nuts, resins, oils, and so forth. In any event, CALM has no jurisdiction over privately owned agricultural land. Consequently, farmers wishing to tackle land degradation with agroforestry techniques receive very limited advice from either department. The clear danger is that the problems that LMS and the Soil Conservation Districts were set up to solve may not, in fact, be solved. If so, farmer disillusionment will be swift. The Department of Agriculture would find it doubly difficult to regain lost confidence, and the land and people of Western Australia would be the losers.

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14. Williamson and Bettenay, note 7 above.

15. See the discussions in A. J. Conacher, "Dryland Agriculture and Secondary Salinity," in W. Hanley and M. Cooper, eds., *Man and the Australian Environment* (Sydney: McGraw-Hill, 1982), 113-25; and Conacher, note 11 above.

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Overview

(continued from page 3)

The discovery phase of that case has revealed the secretive history of the Friant contract renewals and the high-level lobbying over NEPA compliance. As early as 1985, four years before the expiration of the first Friant contract, the bureau met with water users to discuss renewal. In June 1986, the bureau advised the Friant contractors that they must comply with the National Environmental Policy Act. There was still ample time to complete an EIS and consult with FWS on endangered species before any of the contracts expired. Rather than move forward with the process of environmental review, however, the bureau spent nearly two years privately discussing with the water users major terms and issues in the renewal contracts as well as whether the bureau could avoid a full EIS. Meanwhile, the bureau prepared a draft environmental assessment (a precursor to a full-scale EIS) under NEPA and a draft biological assessment under ESA. These drafts examined the impacts of all the renewals taken as a whole and included a "no renewal" alternative.

In November 1987, lobbyists for the water users urged Bureau Commissioner C. Dale Duvall not to conduct any major environmental review. Apparently, water users opposed the preparation of any environmental document for fear that environmental groups might challenge the adequacy of an environmental assessment or an EIS.

In April 1988, Duvall suggested that the water districts were not automatically entitled to the same quantity of water contained in the original contracts. Within a few months, however, the bureau abandoned its draft environmental and biological assessments and indicated that it would seek separate categorical exclusions exempting each contract from NEPA review. Similarly, it decided to do only abbreviated, informal ESA consultations on each separate contract and look only at impacts within each individual district. In effect, the bureau decided it would be easier to claim that contract renewals were not "major federal actions"—and therefore were not subject to the requirements of NEPA—than to try to justify the renewals in light of a full study of the environmental consequences.[11]

After tentatively deciding to abandon the environmental review processes mandated by NEPA and ESA, the bureau asked Ralph Tarr, the Interior Department's solicitor, for a formal opinion on the NEPA issue. The opinion, which was issued a week after a "final" negotiated contract had already been released to the public for comment, rejected the advice of EPA and FWS and up-