Treatment of Salt-affected Soils under Irrigation in the U.S.S.R.: Any Lessons for Australia?

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Visits by many Australian specialists to the U.S.S.R. and vice versa have so far been the main outcome of the Australia-U.S.S.R. Agreement on Scientific and Technical Cooperation, signed early in 1975. Agriculture is involved in three of the five designated fields of interest. For one of these — plant industry research — Evans (1975) listed the topics mutually acceptable for exchange visits. They include reclamation of saline soils; we were chosen as the Australians to start work on this matter.

Our visit to the U.S.S.R. in May 1978 was arranged through the Australian Department of Foreign Affairs and the U.S.S.R. Ministry of Agriculture. In little more than 3 weeks we travelled with an interpreter to Armenia, Uzbekistan, and southern Ukraine, as well as spending some time in Moscow. Interviews across the table at 13 institutions took up most of our working time; opportunities for field inspections were limited to a few experimental areas and an irrigation project under construction.

This paper offers some of our own observations, but it is substantially a summary of information given to us in interviews or found in publications. It is intended to represent the current Soviet work in reclamation and to help Australian specialists in deciding what aspects of the Soviet experience merit closer attention — even cooperative projects as envisaged in the Agreement. Many publications in Russian have been consulted, including the 3rd edition of the Great Soviet Encyclopaedia (GSE); a translation is being published in the U.S.A. Specific references are made only to material available in English, either complete papers or abstracts. Comprehensive and up-to-date information on irrigation and reclamation work is apparently not published for the U.S.S.R. as a whole; no doubt visitors to Australia would reach a similar conclusion about the local situation.

Until recently, the Soviet approach to reclamation of salt-affected soils has stressed both the leaching of those under irrigation and gypsum treatment for the unirrigated soils involved. Some change of emphasis seems to have occurred lately, with more attention now to irrigation and less to the dryland use of gypsum. This may be accounted for by the current drive to extend irrigation in the semi-arid belt. According to FAO reports, irrigation in the U.S.S.R. has increased from 93 000 km^2 in 1960 to 145 000 in 1975. Concurrently in Australia the practice extended from 8500 to 14 700 km^2. By 1980 the Soviet area may reach 200 000 km^2 and there are forecasts of double that area by the end of the century.

Different Conditions: Common Problems

The southern parts of the U.S.S.R. have the main extent of salt-affected soils. Two regions present different problems. One involves the drier parts, notably those in Soviet Central Asia (east of the Caspian Sea), where soils have moderate to high concentrations of soluble salts and irrigation is essential for agriculture. The other is the semi-arid belt extending eastward from the Ukraine (Fig. 1); traditional dry-farming there is handicapped by the patchy occurrence of soils whose defects are due to concentrations of exchangeable sodium. These soils, known formerly in many countries as 'alkali' and now as 'sodic', are generally identified in the U.S.S.R. as 'solonetzic' and can be improved by chemical treatment.

Many Soviet irrigation schemes are linked with power generation and some are tied in also with the provision of navigable waterways. The capital works involve thousands of engineers,

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drains; we saw these being constructed in advance of irrigation. They are provided at the rate of 40 to 80 m ha^{-1}, the alternative being vertical drains at the rate of one tube well to each 100 ha. All drainage effluent, whether from these new systems or the open horizontal drains still used in older parts of the Hungry Steppe, goes via the main drains, known as collectors, into either the river towards the east or a saline depression at the west serving as an evaporation basin.

The principal measures for treatment of new land in the district have been land levelling, installation of drains at an average depth of 2.5 m, leaching with at least 15 ML ha^{-1}, and sowing rice for 1 year or lucerne for 2 as a green manure crop. Then cotton may be grown consecutively for 6 or 7 years, though satisfactory yields are not expected for the first three crops. Eventually a rotation system is established, using maize, sorghum, vetches, mustard, or grains in conjunction with cotton. The complete cost of developing farms on unused land is given as *c.* \$A12 000 ha^{-1}, including provision of roads, water supply and housing. Incidentally, the use of land and water has been without charge since the Soviet revolution.

Salt Pollution of Rivers

Water quality in Central Asia is reported in several publications. According to data given by Alimov and Inogamov (1971), the salt content of water supplied to the Hungry Steppe in 1969 was 0.8 g L^{-1}, while the drainage water had 2 g L^{-1}. Orlova and Dunin-Barkovskaya (1975) reported that the principal upstream tributaries of the Syr Darya had average salinity well below 0.5 g L^{-1}, but at Kazalinsk near the Aral Sea the concentration in the river exceeded 1 g L^{-1}. They also stated that at Kazalinsk the salinity was below 0.5 g L^{-1} in 1911–12, but increased to 0.7 in 1950 and to 1.2 in 1970; they estimated 2.0 g L^{-1} as the concentration for 1975. The contribution of irrigation and drainage to this situation is shown by the report (GSE) that the draw-off to irrigate 2.2 million ha from the Syr Darya in 1970 was 40 km^3, while the return flow to it from drains was 13 km^3. Other details about the salinity of this stream are given by Stepanov and Chembarisov (1978). The quality of water in the Amu Darya is not reported so well. Some information (Revina and Soloveva 1970; Hollis 1978) suggests that up to 1970 it was supplying the Khorezm oasis in its delta with water of moderate quality (salinity *c.* 0.5 g L^{-1}). However, V. A. Kovda in a 1978 issue of *Pochvovedeniye* reports its salinity as now exceeding 1 g L^{-1}, the same as for the Syr Darya.

New irrigation projects in Central Asia must add to the problems of water quality. Four more large schemes may provide another million ha to the irrigated area in Uzbekistan. They involve the Dzhizak Steppe on the southern margin of the Hungry Steppe, the Karshinski Steppe southwest of Samarkand, the Surkhan-Sherabadski Steppe south of Samarkand, and the Khorezm oasis. The first three concern loessial loams near the mountains and two require pump stations to lift water more than 130 m.

Siberian Rivers to the Rescue?

The steady increase in irrigation must weaken the downstream flow of rivers concerned, increase their salinity, and reduce the level of the Aral Sea. The remedy favoured among many irrigation specialists is to divert Siberian river water to the region, a matter considered by Shults (1968) and Hollis (1978) and currently much discussed in the U.S.S.R.

Armenia

The Armenian Soviet Socialist Republic occupies a small and mountainous area of 30 000 km^2, i.e. about half the size of Tasmania or smaller than the Netherlands. Altitudes range from 400 m on the Ararat plain to 4090 on Mt. Aragats, not 50 km away. Mean annual rainfall on the mountains may exceed 900 mm, three times as much as on the plain. Irrigation was used at least 2500 years ago — a substantial canal of that age can be seen near Yerevan. Water is available from many streams and springs. Arable land now totals 400 000 ha, with more than half under irrigation and much made suitable for cultivation only at great expense in removing boulders from uplands. The flatter lowland most eligible for cultivation is generally the most in need of water for crops and very likely to have salinity problems. Salt-affected land awaiting reclamation amounts to 30 000 ha on the Ararat plain near the capital city, Yerevan. Success in dealing with this land, now useless, would add considerably to agricultural production in Armenia. The problem soil is highly sodic, apparently as a result of accumulation of carbonate from shallow groundwater highly charged with bicarbonate and carbonate.

Countering Sodicity

Varied and prolonged efforts have been made towards improvement of this land. Encouraging results were obtained in the 1950s by G. P. Petrosian, who established vines and fruit trees in trenches made by removing the saline topsoil to unwatered banks alongside. His experimental garden still flourishes. After relatively fruitless efforts at large-scale reclamation elsewhere on the plain by applying gypsum, success was achieved using sulphuric acid or green vitriol (ferrous sulphate heptahydrate). Both materials are available as waste products from industries in the U.S.S.R. In 1969, during the Yerevan Symposium on Reclamation of Sodic and Soda-Saline soils, Petrosian and Tchitchian (1969) reviewed the local methods of reclamation. Further developments were reported by Petrosian (1976). The total area reclaimed in 20 years and now under production is said to be 2000 ha.

Use of Acid and Green Vitriol

The reclamation involves application either of dilute acid (1%) at the rate of 9 ML ha^{-1} or of green vitriol applied at 200 t ha^{-1}. Then follows heavy leaching with water of suitable quality at 30 ML ha^{-1}, to horizontal drains arranged to keep groundwater at least 2.5 m below the surface. Before treatment the soil pH ranges from 9 to 11; after reclamation it falls to 7 or 8. At the Yeraskahun Reclamation Experiment Station, conducted by the Armenian Research Institute of Soil Science and Agrochemistry, 200 ha of useless land are now producing vegetables, fruit, cereals, and rose pelargonium (perfume) crops (Fig. 2). The reclaimed land is now permeable enough for growth of sensitive plants like apricots, though the small reserve of untreated land on the station will show pools for hours after a light shower of rain (Fig. 3), even though the soil profile is loamy to at least 2 m. We could not judge how representative this station is of the problem land in the district, but from its position close to an old stream channel, it may correspond to the better drained and coarser textured soil situations in the area, like those found on the levees of poorly incised streams (prior streams) on the Riverine Plain of south-eastern Australia.

The costs of reclamation and irrigation development are given as equivalent to $A6000 for 8000 ha^{-1}, not including any charge for the required waste products, said to be delivered free to the local railway siding. Agricultural economists in Armenia claimed that the investment is repaid after 5 years' production, especially when raising profitable per-

Fig. 2. Irrigated potatoes on the Yeraskahun Reclamation Experiment Station of the Armenian Research Institute of Soil Science and Agrochemistry.

Ерасхаун

Fig. 3. A corner of the reserve of untreated saline land with tamarisks, sedges, and bare ground on the Yeraskahun Reclamation Experiment Station. Note rainwater ponded in foreground.

fume crops. This type of reclamation with acid or green vitriol is not a local or new development, as the Armenians freely admit. These ameliorants were used in the U.S.A. during the 1920s (Kelley 1951) and by 1950 they had been tried in other parts of the U.S.S.R.

Water Management Determines Reclamation

The important problem now is the water management involved rather than the chemical treatment. A considerable amount of water is needed for leaching, after which it becomes a burden for drainage and disposal. Despite Armenia's good fortune in having Lake Sevan to supply water for power generation and subsequent gravitation to irrigation areas and town waterworks, the water resources of the republic are not so abundant that the land can be reclaimed quickly. With water freely available it would take 10 years to treat the whole area of problem soils, but it may actually take 15 to 20 years in view of the need to satisfy more urgent needs for Armenian water. At present the Yeraskahun Station is able to use underground water with sufficient pressure to rise above the surface. Some irrigation is carried out there with this water in a mixture with drainage water.

Southern Ukraine

Handicaps of Climate and Soil

The lowlands near the Black Sea are a small part of the semi-arid country which extends easterly past Volgograd into Kazakhstan. It is noted for wheat production and frequency of droughts. Kherson, our point of contact with this land, has a mean annual rainfall of 340 mm; for the period 1886 to 1954 its drought frequency was 30% (Lydolph 1977). The rainfall at Volgograd is 319 mm and Tselinograd, in the one-time 'Virgin Lands' of Kazakhstan, receives 300 mm. There is a transition from black soils (chernozems) in the north to dark brown (chestnut) soils in the south, but throughout this extensive belt of country there are patches of sodic soils with crusty surfaces, cloddy subsoils, and appreciable contents of exchangeable sodium — three attributes of soils described in the U.S.S.R. and elsewhere as solonetzic. A considerable part of the lowlands of southern Ukraine is covered by these soils which have a reputation for giving the poorest crop yields. Their reclamation by treatment with gypsum was investigated widely between 1930 and 1950. Effective procedures were developed to improve the soil properties and crop yields, as reported by Kovda *et al.* (1973), but it takes several years for the treatment to make its full impact in the drier districts. Despite the availability of water in large rivers like the Dnieper, whose mean annual discharge is twice that of the Murray in south-eastern Australia, irrigation was not important in the Ukraine before the last war.

Recent Turn to Irrigation

Nowadays the improvement of solonetzic soils in southern Ukraine is being considered increasingly in the context of irrigation. This has extended tenfold from 200 000 ha in the Ukraine in 1956. For the whole of the Republic only 5% of the arable area is watered, but near the Black Sea the proportion now ranges from 10% in the Donetz district to 25% in northern Crimea. The main source of irrigation water is the Kakhovsk reservoir on the lower Dnieper. It was completed in 1958 and has a capacity of 18 km^3 — six times that of the Hume reservoir on the Murray. Water from the Dnieper river thus supplies the nearby Kakhovski irrigation system and 175 000 ha in northern Crimea and the Krasnoznamenski district. These two irrigation areas are supplied by long canals — one extends as far as Kerch at the eastern end of the Crimean Peninsula.

Research at Kherson

The perspective for irrigation in this part of the U.S.S.R. is not limited to supplementary watering; the intention is to intensify the use of irrigated land by gaining two or three harvests in a year. Relevant problems are investigated at the Institute of Irrigated Agriculture, which was established in 1956 and has its headquarters and experimental fields on about 800 ha at Kherson. Many aspects of the irrigated production of grain, forage, and potato crops are investigated there. The cereal-breeding program, for example, has a target of 5500 kg ha^{-1} for irrigated winter wheat, and their best variety so far has produced about 5000 kg ha^{-1} under experimental conditions. Field trials at the Institute deal with crop rotations, fertilizer requirements, water supply, weeds, pests, and disease control. Supplementary laboratory services are provided within the Institute grounds by one of the many agrochemical service laboratories controlled by another Institute based in Moscow.

Solonetzic Soil — a Problem for Irrigation

A complication for irrigation of this semi-arid land arises from the patchy occurrence of the solonetzic soils, whose rates for water infiltration are inferior to those of the other soils nearby. Uneven entry of water leads to soil erosion in some places and waterlogging in others, so it is important to improve the problem soils and to provide suitable equipment for sprinkler irrigation. This method of watering is used in the Ukraine on all but the small area of rice under flood irrigation. Treatment of the solonetzic soils depends mainly on the introduction of gypsum to the topsoil, either by a special application of the material or by transferring it from a subsoil horizon by means of a special plough designed to avoid burial of the topsoil after this operation. Some use is also made of ferrous sulphate, lime, and calcium chloride. Much progress is claimed in the treatment of these soils, but setbacks have occurred through the appearance of soda salinization after irrigation.

A sound basis for judging a soil as solonetzic is important for the practical steps required in reclamation. There are conventions about rating these soils: a weakly solonetzic soil in the U.S.S.R. should have an exchangeable sodium percentage (ESP) of 5 to 10 in the dense subsoil, and more than 25 is required for a soil to qualify as strongly solonetzic or as a solonetz. Another approach is proposed by Dr Laktianov of the Institute we visited at Kherson. In dealing with soils having ESP of 10 to 12, he found that the best criterion of solonetzic properties was not ESP but the content of peptized highly dispersed particles, to be determined by micro-aggregate analysis (Laktianov 1962).

Water Quality and Drainage

Irrigation in southern Ukraine involves the usual considerations of water quality and drainage. River water is mainly of good quality, e.g. irrigation water from the Dnieper normally has a salt concentration of about 0.2 g L^{-1}, but more saline water from the Ingulets River near Kherson is used in a mixture with Dnieper water. About 30% of the water used for irrigation in the Ukraine is obtained from groundwater resources and farm dams. Some drainage is discharged to the Black Sea basin by open horizontal channels, and vertical drains are used in northern Crimea and other parts where suitable aquifers can be intercepted by the tube wells. There is some use of better quality drainage water for irrigation.

Meliorative Soil Science

Pioneering Work

Scientific data on saline soils and their behaviour under irrigation have accumulated gradually over more than 70 years. Soil surveys in Central Asia were started by N. A. Dimo in 1908 and provided basic information on soil salinity for that region. Problems of salinity under irrigation on the Hungry Steppe came under investigation there at a field experiment station set up in 1913; the influence of saline groundwater was recognized then but not fully understood. It was not until the late 1920s that the idea of a 'critical depth' to the saline water table was formalized by B. B. Polynov. That period was important also for attention to the chemistry of salt-affected soils, notably by Gedroiz, and to the physical aspects involved in controlling salinity. The movement of salts in irrigated areas was given early study by Dimo in Central Asia, but it was left to L. P. Rozov in 1936 to introduce the term 'salt balance' in his book 'Meliorativnoye Pochvovedeniye' ('Meliorative Soil Science'). Rozov and A. N. Kostiakov (1886–1957) made contributions that were helpful for land drainage — important both for irrigated lands in the south and for swamps to be reclaimed in the north. These men were closely associated with the Research Institute of Hydrotechnics and Melioration, based in Moscow and now named for Kostiakov.

Research of wide significance for salinity reclamation was carried out from the Dokuchaiev Institute of Soil Science, established in Leningrad during 1927. Members of its expeditions to the steppes and deserts made soil maps and sent back soil samples for consideration by specialists in soil salinity, including Gedroiz and Antipov-Karataev. Contributions concerning Central Asia, the Volga region, and other parts were completed in this way, usually with some involvement of local research groups.

Long Controversy about Drainage

By the 1930s the upsets to irrigated agriculture from the earlier war and revolutionary struggles had been overcome and some advance on pre-war achievements had been made, despite the constant problem of salinization. A representative conference in 1936 on this problem was important for showing the two opposing schools of thought. One was led by V. R. Williams whose agricultural doctrine then in vogue — the travopolye system of farming — emphasized crop management and rejected any general need for drainage of irrigated land. The other involved L. P. Rozov and fellow-advocates of land drainage. That debate brought victory to the Williams school, but the controversy continued until 1964 when resolved in favour of drainage (Yegorov and Minashina 1967). This is now a cardinal principle of meliorative soil science — to use the term favoured by Kovda, Yegorov and others for the science of land reclamation, oriented to practical objectives.

Institutes of Soil Science

Meliorative soil science is associated particularly with the Dokuchaiev Institute, now located in Moscow. This is a well-known centre of soil research, with decades of experience in soil salinity problems. It has close ties with other groups involved with reclamation. Notable among these is one in the Research Institute of Soil Science and Agrochemistry at Tashkent, which follows on from Dimo's group working there from 1920 in the first university set up in Central Asia. Several other Institutes of Soil Science are involved in reclamation research, e.g. at Alma Ata, Baku, and Yerevan. The topic is also developed in several other establishments, especially the Central Asian Irrigation Research Institute, founded in 1925 at Tashkent.

Publications

Scientific reports on melioration appear frequently in the monthly journal *Pochvovedeniye*, much of which is translated and appears in the U.S.A. in *Soviet Soil Science*. Reports are also published occasionally in other journals and as monographs. There is overlap with considerations of reclamation from hydrotechnical and agronomic viewpoints; these are catered for in particular journals. Many details of relevant Soviet investigations are indicated in an international source book (Kovda *et al.* 1973).

Conclusions

The resources of land and water in the U.S.S.R. seem adequate for considerable extension of irrigation. Experience so far, however, suggests that such development would add considerably to the problems of reclamation which is no longer a matter of treating a particular area in isolation from its hydrological environment. Variation in the landscape units of the U.S.S.R. and their geochemical settings presents the Soviet specialists with a range of problems apparently wider than in Australia. Sulphate, chloride, and carbonate types of salinity each occupy substantial areas in the U.S.S.R., whereas Australian problems seem to come mainly from chloride salinity associated with highly mineralized groundwater, especially that trapped in parts of the Murray Basin.

Irrigation of wheat lands in the dry steppes is likely to extend in the U.S.S.R., with the prospect that farm managers not familiar with the pitfalls of irrigation may face outbreaks of carbonate salinization. The lure of irrigation for a district prone to droughts is certainly attractive, especially where water is available free from magnificent rivers. The Australian experience of comparable country points to the difficulties that arise when an irrigation scheduled on average expectations of weather is followed by unexpectedly heavy rains.

Reducing Seepage

Soviet irrigation projects have had their share of troubles caused by seepage from main supply canals and district channels. This has led, as in Australia, to various ways of reducing seepage losses and improving the efficiency of the supply system. Piped supplies are being introduced in the U.S.S.R., especially for sprinkler irrigation and sub-irrigation. Schemes for automatic control being developed for these two methods should be of interest in Australia.

From Research to Practice

Soviet soil specialists generate and publish numerous data in their reports. They give details relating to soil salinity, e.g. the concentrations of the predominant ions, profile morphology, exchangeable sodium percentage, particle-size composition, etc. Fairly detailed classifications of salt-affected soils have been developed and new schemes are proposed from time to time. All this material is certainly valuable for the specialists in meliorative soil science, but problems must arise in passing on the message to the people concerned with day-to-day management of the problem soils. One safeguard is by way of transfer of personnel from research to irrigation management; this has happened in Australia. Unfortunately, we had no opportunity to find how reclamation was viewed and dealt with on farms in Soviet irrigation areas.

River Management in Central Asia

The specialists in reclamation concenttrate on the existing irrigation areas and planning for further extensions. In recent years they have been made aware that irrigation and drainage can bring serious deterioration to land and water in the lower reaches of the streams concerned. The evidence mostly referred to in our interviews or in publications relates to Central Asia, especially the Syr Darya river as mentioned above. In terms of overall salinity expressed as total dissolved salts, the downstream tract of this river now gives water of poorer quality than comparable parts of the Murray River. According to data in the last 10 annual reports of the River Murray Commission, the mean monthly salinity at Murray Bridge has been 0.4 g L^{-1}, with 0.7 as the mean for the drought year 1967–68 and 0.9 as the maximum value in February 1968. A good comparison would require similar impurities in the two streams, but it is known that the more saline water from the Murray is rich in sodium and chloride while that from the Syr Darya has predominantly sodium and sulphate.

The Soviet problems with the supply and quality of river water are so far confined mainly to Central Asia. Specialists of that region see the solution not by modification of plans for extending the irrigation and reclamation of saline lands, but through diversion of Siberian river water. This view seems to be accepted among soil scientists, whose main concern about reclamation continues to be the choice of water supply schemes and drainage systems for improvement of agricultural production.

Soviet Emphasis on Groundwater and Drainage

The present generation of leading specialists in meliorative soil science appears to be still involved with the consequences of the earlier rejection of drainage. Emphasis then was placed on reducing the supply of water in order to minimize the rise of watertables, but the scheme was impractical and unsuccessful, at least near Merv (Minashina 1977). In the contemporary view it is accepted that irrigation efficiency must be improved, but the central questions of melioration are the depth to groundwater and its salinity (Kovda 1977). Consideration has been given to current proposals in the U.S.A. (e.g. Branson *et al.* 1975) for reducing discharge of salt from irrigated land, but they are regarded as generally inapplicable to the Soviet conditions of marked complexity of soil cover or the presence of shallow saline groundwater (Minashina 1977).

U.S.S.R. and Australia

The cost of irrigation and reclamation in the U.S.S.R. is regarded there as justified by the promise of adequate yields for the commodities in demand, especially cotton and cereals. The policy is to make the most use of the abundant resources for irrigation and to meet the allied problems of reclamation at least by making the necessary drainage installations and introducing suitable cultivation machines and soil ameliorants.

Notwithstanding the different type of irrigated agriculture widespread in Australia, Soviet specialists in reclamation should generally be familiar with the breadth of discussion shown at a recent symposium (Storrier and Kelly 1978) concerning an important Australian irrigation area. What they would probably find beyond their experience is the prolonged disagreement among the four governments involved with irrigation in the Murray River basin over measures to safeguard the irrigation areas and the quality of the water supply.

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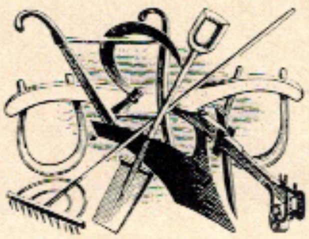

'But wiser discerners do well understand that every art hath its own circle, . . . that strict and definitive expressions are always required in philosophy [science], but a loose and popular delivery will serve oftentimes in divinity.'

— Sir Thomas Browne
(1605–1682)